CHAPTER 3.--SOLUTIONS TO THE COMMUNICATION REQUIREMENTS

3.1 Introduction

Three types of communication systems have become popular in solving communication requirements underground: Loudspeaking pager phones, carrier current phones, and magneto ringing phones. Basically, all three are simply single-channel party line systems. Although these systems are quite reliable, the single channel creates a variety of problems. For example--

1. Since no call is confidential, messages are sometimes purposely made vague, especially if accidents or safety topics are being discussed.

2. A potential user must literally "wait in line" until the channel becomes clear for his use; thus, when foremen have to wait to call in reports or supply requests, this single chan-nel creates a serious productivity bottleneck.

3. In many large mines, there are independent branch lines that must be tied together by a dispatcher, adding further delays to the system.

To solve these problems, some mines have installed other phone systems--mostly commercial dial phones in industrial enclosures that offer extra channel capacity and private line features. Others have installed a system that combines both dial- and page-phone features in a single unit.

Although these do represent improvements, they do not truly solve the overall problems that face modern mines. Besides extra channels, a communication system should have the following features to enhance productivity and safety:

1. A means of paging a roving miner to alert him that he is wanted on the phone.

2. Wireless-to-wired system interconnects by which a miner can talk on the wired phone system by using a remote portable radio.

3. Remote monitors that alert personnel when there is a toxic or explosive gas buildup.

4. Control interfaces that allow remote control of fans, pumps, or other devices.

5. Transmitters and receivers that can serve as emergency links.

6. Loopback that allows an alternate path of communications if the main path is cut.

This chapter focuses on equipment and methods to meet the special communication needs of individuals in various places of the underground mine. The communication requirements can be broken down into four categories:

1. The mine entrance (shaft communication).

2. Permanent and semipermanent locations (shop areas, lunchroom, crusher stations, etc.).

3. Mining areas (the room-and-pillar sections, longwall faces, block caving areas, etc.).

4. Haulageways (tracked trolley haulage, diesel, belt haulage).

Methods of implementing systems to meet the communication needs of these areas are described in sections 3.2 through 3.5.

Section 3.6 discusses methods of satisfying special communication requirements that exist. Major topics in this category include communications with roving personnel, the isolated miner, and motorman-to-snapper communications.

Emergency communication systems are described in section 3.7. Detecting and locating the trapped miner, rescue team communications, and emergency warning systems are discussed.

Although the methods of establishing communications throughout a mine are broken down and described in separate sections, as outlined above, it is important to realize that these systems should be tied together or interconnected in some way. The overall design plan must include provision for integrating the various communication subsystems together into a minewide system. Such a system, designed with the total mine operating plan in mind, will be the most effective. In a like manner, a judicious choice of monitored parameters in the underground environment and selected machinery will yield a cost savings in production and augment safety. Many man-hours and dollars can be saved by knowing conditions before they become a problem. Situations that could become disastrous can be predicted and proper solutions implemented before the disaster occurs. Because proper environmental and machine monitoring and control is another key to safer and more productive underground mining, these factors should also be considered in the overall plan of any communication system.

3.2 The Mine Entrance

The entrances to underground mines are either vertical shafts, slope entrances, or horizontal drifts. Slope and horizontal drift entrances can be considered as a continuation of a haulageway and are treated in section 3.5. This section is devoted primarily to shaft communications.

In the past, operators of single-level mines with overburdens less than 1,200 feet have felt that communications between the top of the shaft, the bottom, the hoistroom, and possibly a communications center were adequate. Many mines in this category (which includes most underground coal mining operations) did not have the capability of two-way voice communication with personnel in the cage.

One of the biggest reasons for this deficiency in communications to and from the cage has been that reliable equipment simply was not available for establishing this vital two-way voice communication link. This reason is no longer valid. Today, equipment is commercially available to implement effective two-way voice communication, even while the cage is moving, down to depths in excess of 10,000 feet.

A useful hoist-shaft communication system must satisfy the requirements for communication throughout the full travel of the cage, providing voice communication between the cage and the hoistman, as well as to underground shaft stations. An effective system should also provide for shaft-inspection communication between the inspector and the hoistman, and should have a slack-rope indication. For the modern, automated shaft, signals are also required to permit selection of level, enable interface with interlocks, and permit jogging for exact position at any level.

The limited space within the cage places an operational restraint on equipment. Equipment must be small and should be located so that it cannot be damaged by any of the various uses of the cage such as transporting supplies and machinery. An additional microphone-speaker station may also be desired for multi-level cages or when several cages are joined together.

A reliable hoist-shaft communication system should be considered as a vital part of any overall communication system. Shaft communication is especially important during or following an accident or disaster situation. Experience has taught that the hoist often becomes a bottleneck during rescue or evacuation operations, and good communication to and from the cage is essential.

Traditionally, bell signals have been used between those requesting the cage and the hoistman, and until recently, bell signaling was usually the only form of hoist-shaft communication.

Today, however, equipment is available that allows two-way voice communication between persons in the hoist cage and the hoistman or other locations at the shaft top or bottom.

Presently available methods of implementing two-way voice communication with the hoist cage include trailing cable systems, radio systems, and hoist rope carrier current systems.

3.2.1 Bell Signaling Systems

There was a time when bell signaling was the only form of communication between those requesting a cage and the hoist operator. Because of this, bell signaling systems have gained widespread acceptance and are used on many hoists.

Figure 3-1 shows a simplified schematic diagram of a typical shaft buzzer signaling system. In the system depicted, a single twisted pair wire is run down the mine shaft and "tapped off" at those shaft stations where signaling is required. Figure 3-1 shows a system with the twisted pair tapped at three levels

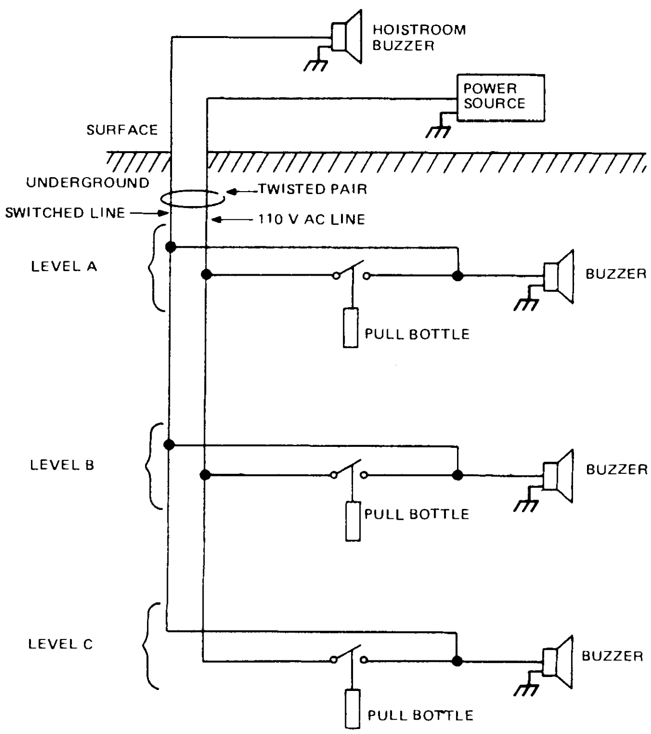

FIGURE 3-1. - Bell signaling system.

(level A, level B, and level C). To signal the hoist operator, a miner at any level pulls the pull bottle, causing the associated switch to close. This applies voltage to the buzzer at that level, and also to the hoistroom buzzer and all other buzzers, through the switched line of the twisted pair.

Bell signaling systems, although proven to be reliable, do have some severe shortcomings. First, there is no way to convey special messages to the hoistman. Special equipment or assistance or unusual cage movements cannot be requested unless a signaling code has been defined for that specific request. A second disadvantage, especially for mines with many shaft stations, is that the bell codes required can become quite long. Long or complicated bell codes are obviously more difficult to remember and can become a source of confusion, especially during an emergency or disaster situation. During these critical periods of high emotional stress, mistakes are easy to make even when signaling codes are posted. Some mines with many levels and/or shaft stations have partially overcome this disadvantage by assigning an employee to the hoist cage. Because this miner, called a cager, is permanently assigned to act as the hoist cage operator, the bell signaling code has become "second nature" to him.

Another disadvantage of the bell signaling system is that communication with the cage is impossible when it is between levels. This deficiency is especially crucial during shaft inspection or repair. Some mines have partially overcome this problem by running a pull cord down the shaft. This cord is kept in a position next to the shaft timbers by staples and can be used for emergency stops and signaling between shaft stations. This system does provide some degree of emergency communication from the cage while it is between shaft stations; however, operation of the system can be extremely dangerous since it requires the operator to reach out of the cage and grab a cord, which may be moving relative to the cage.

3.2.2 Trailing Cable Systems

One method of establishing two-way voice communication with the hoist cage is by using a trailing cable. In this type of system. A communications cable is physically attached to the bottom of the cage and allowed to hang down the shaft below the cage.

Figure 3-2 shows a typical trailing cable system. In the figure, three phones (one in the hoistroom and one at each of the two shaft stations) are connected by a phone line that has been strung down the shaft to a junction box located about halfway down the shaft. Connections are made within the junction box to the trailing cable which provides the link to the phone mounted in the cage. The trailing cable system can be tied into the existing wired communication system in the mine, or it can be implemented as an independent, shaft-only, communication system.

In addition to the disadvantages associated with any wired communication system (normal cable maintenance and line breaks), the trailing cable system has limitations in terms of depth because of the amount of cable that can be trailed from the cage.

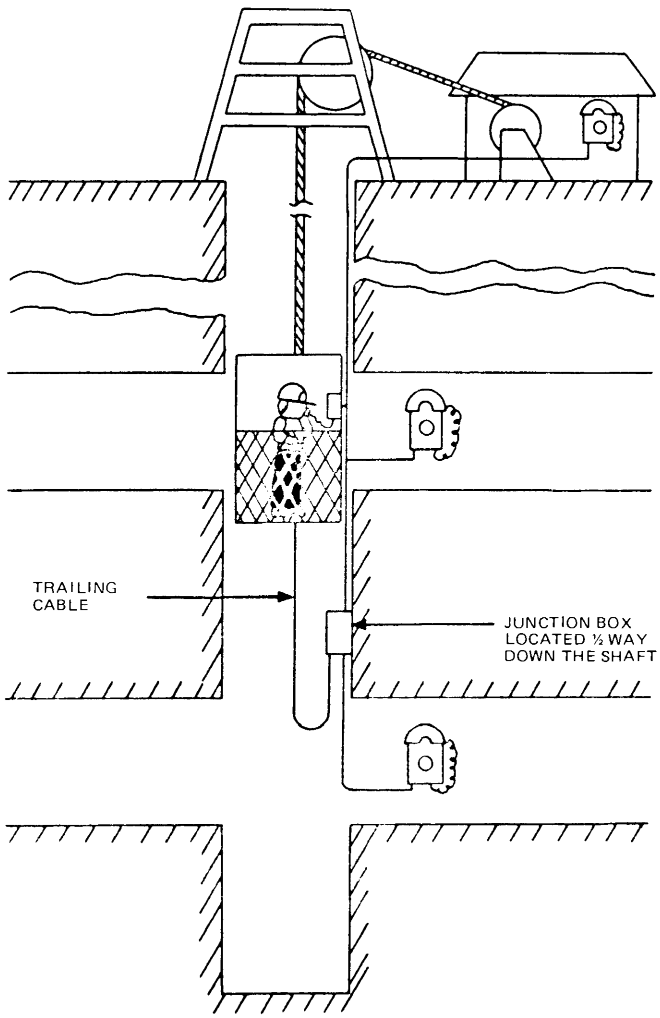

FIGURE 3-2. - Trailing cable system.

3.2.3 Radio Systems

Another approach to satisfy the voice communication requirements with personnel in the cage is by using two-way radio systems. Some recently installed radio systems are meeting the hoist communication requirements. One radio system currently being used at an iron ore mine is illustrated in figure 3-3. In this system, portable police-type 150-MHz FM radios were used in 19-foot-diameter shafts. The surface antenna is a dipole mounted on plywood bolted to the steel collar at the top of the shaft. A coax runs from the dipole to the hoist room, a distance of about 500 feet. In the cage, the radio and 12-volt battery are mounted in a plywood box.

Results of studies indicate that the attenuation of radio signals increases

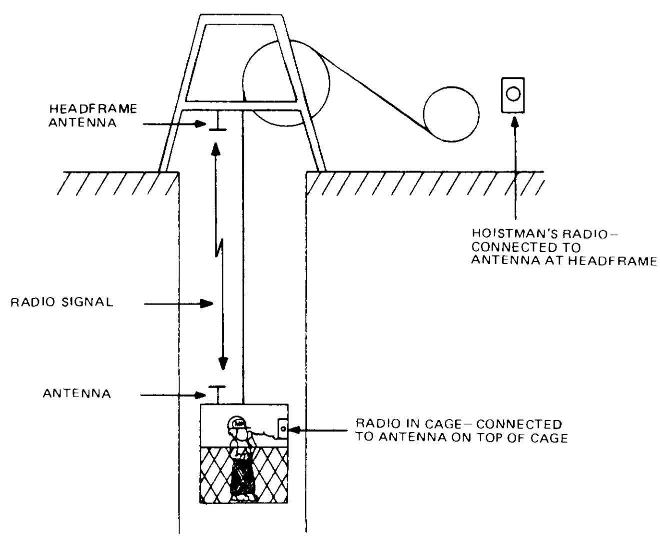

FIGURE 3-3. - Hoist cage radio.

sharply as shaft size is decreased. For straight, unobstructed shafts with a diameter in the neighborhood of 12 feet, radios operating in the frequency range of 500 to 1,000 MHz should provide communication to a depth of approximately 1,500 feet. For smaller diameter shafts, radio communications will only be possible over shorter distances.

3.2.4 Hoist Rope Carrier Current System

A carrier current system using the hoist rope as the carrier has been developed that provides reliable two-way voice communication between the cage (even while in motion) and the hoistman to cage depths in excess of 10,000 feet. The principle of operation of the hoist rope carrier current system is similar to that of the carrier current commonly used in trolley carrier phone systems. Both systems transmit and receive RF energy over a transmission line. In a trolley system, the transmission line is the trolley wire. In the hoist system, the carrier signal is transmitted on the hoist rope. Both systems utilize transmitters and receivers (transceivers) that communicate with each other by RF currents superimposed on a cable.

The principal difference between the trolley carrier system and the hoist rope carrier system is the way in which RF energy is transferred to, and received from, the transmission line. Because the hoistman's transceiver at the headframe cannot be physically attached to (or even touch) the hoist rope, a different method of superimposing RF energy onto the rope must be used.

The solution is to inductively couple the hoistman's transceiver to the hoist rope. Figure 3-4 shows a block diagram of a hoist rope carrier current system. The system consists of two signal couplers and two transceivers. Each transceiver is of the push-to-talk, release-to-listen design. During transmission, the sending transceiver feeds its coupler with an FM carrier. The coupler induces a signal into the hoist rope, which travels up and down the hoist

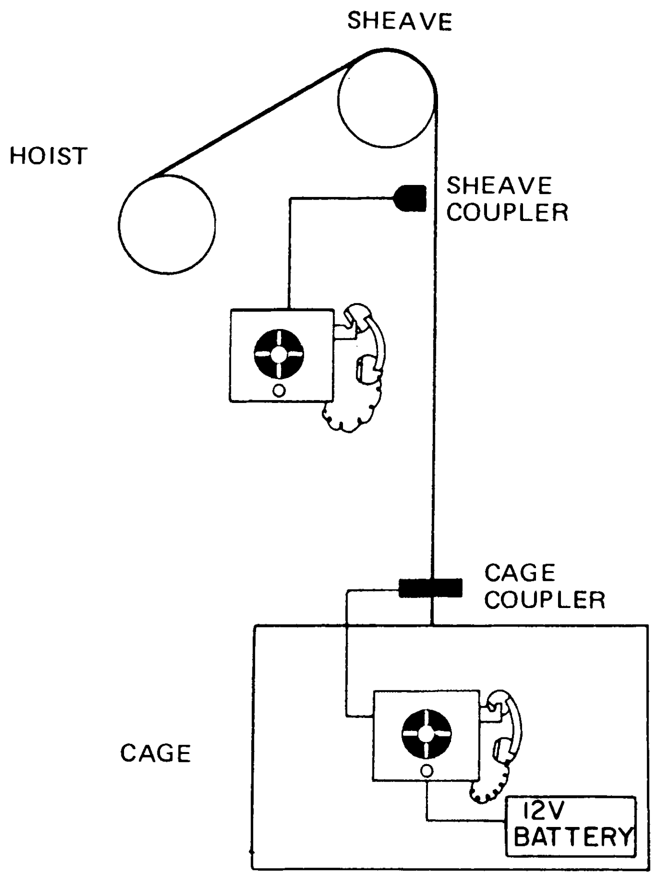

FIGURE 3-4. - Hoist rope carrier current system.

rope and is picked up by the coupler at the other transceiver. Each coupler operates as both a transmitting and receiving element. The cage coupler is clamped to the hoist rope at a point just above the cage. The coupler for the surface transceiver should be permanently mounted below the sheave wheel and about 6 inches from the rope. Coaxial cable should be used to connect each coupler to its transceiver.

3.2.5 Hoist Signaling Summary

The pull-bottle shaft bell has been the universally accepted means of cage signaling. More than 60% of the hoists, notably those in bedded deposit mines, have only one underground level; hence this type of signaling system is simple and effective. In multilevel mines, signaling codes become complex to the point where a full-time cageman may be required to control the cage during all man and equipment lifts. Depending on the size and nature of the shaft, commercial radio equipment operating at 150 or 450 MHz can provide a voice link down to 2,000 or 3,000 feet.

For a very deep (2,500 feet or greater) or narrow shaft (less than 10 feet in diameter), communication systems are available that inductively couple RF signals to the hoist cable. These carrier current systems provide two-way communication with the cage in even the smallest shafts down to depths in excess of 10,000 feet.

3.3 Permanent and Semipermanent In-Mine Locations

Looking only at the permanence of a telephone installation, phone locations can be divided into the following three categories:

Permanent (life of the mine).

Semipermanent (more than a year between moves).

Frequently moved (weekly to monthly).

Permanent locations include surface sites, the dispatcher's station, underground offices and shop areas, lunchrooms, rail or belt heads, storage areas, the crusher operator, and along main haulageways.

Semipermanent phones would be found mostly in the submains of a mine. After panels have been fully developed, most of the phones in the submain would be relocated to more active sections. One or two phones would remain for use by roving personnel. If a submain became part of the haulage system, in all likelihood more phones would remain in use to meet the operating practices of the mine.

Frequently moved phones are primarily located near the working faces of the mine, typically in working sections off submains. These phones are moved with the section in order to maintain close communication with the dispatcher, maintenance, and management personnel. Communications equipment associated with advancing or frequently moved face areas is treated in section 3.4.

The single-pair wired phone system is the communication system commonly employed to satisfy the requirements of permanent locations. Magneto phones were first used, but although many are still in use, they have been largely replaced by loudspeaking pager phones.

In a few mines the conventional telephone with a rotary dial and ringer (mounted in an explosion-proof housing) has been used. Systems using these dial phones are usually an extension of an aboveground private automatic branch exchange (PABX) or a single-party independent system with a small switchboard. Recently multipair cable and even multiplex systems have been used to interconnect phones and to connect individual phones to an aboveground PABX.

3.3.1 Single-Pair Pager Phones

Pager phones were specifically designed to meet the requirements of permanent and semipermanent locations for underground mining operations. They differ from a conventional telephone in that instead of a ringer, a loudspeaker is used in each phone to alert the person being called, and each phone has its own batteries for power instead of being centrally powered. In a single-pair installation, the pager phones are interconnected by a single twisted pair of wires and all phones are on a single party line. A 14- to 18-gage copper pair with a neoprene jacket is most often used.

Figure 3-5 shows a hypothetical, moderate-sized room-and-pillar coal mine with an average working section size of 300 feet by 400 feet, and an average panel size of 800 feet by 1,200 feet.

The upper half of figure 3-5 shows the main haulageway, the operational submains, and the working sections and illustrates how a single-pair pager phone

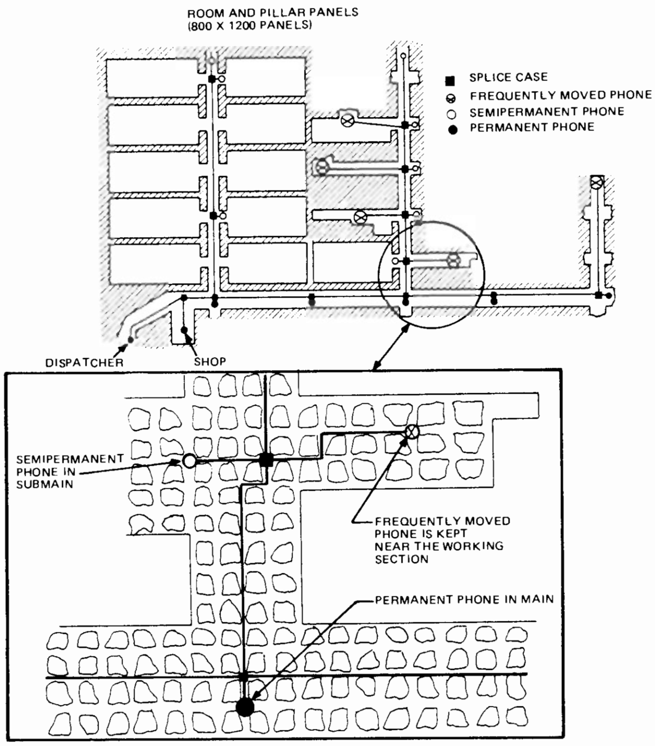

FIGURE 3-5. - Single-pair pager phone installation.

system would be wired. The solid black line represents the single pair. The black squares represent splicing points, and the circles represent the telephones. Telephones can be seen at the dispatcher's office, in the underground shop area, and along the main haulageways; there is one at each butt entry and one near each working section, and a twisted pair is shown running to the pager phone at each working section. When a panel is worked out, the phone at that butt entry may be removed and installed at another location. Usually, as shown in figure 3-5, a few phones are left behind along the submains in worked-out sections. These phones may be used periodically by roving maintenance personnel or inspectors.

A mine is not static; its architecture or layout changes, but fortunately these changes are usually known well in advance so that cable selection and the phone line layout in the mine can be planned to accommodate future growth. As far as changes are concerned, the phones shown in the example of figure 3-5 fall into the three basic categories as follows:

1. Telephones in the dispatcher's office, shop area, and main haulageway, and opposite each submain, would rarely, if ever, be moved (permanent).

2. Telephones opposite each butt entry would remain in place for one year or so until more panels in the submain have been developed (semipermanent).

3. Mine safety regulations require that a communication link must be established within 500 feet of the working face; hence, telephones at the working sections are required to be moved frequently (perhaps once a week).

3.3.2 Multipair Systems

For a multipair access installation (fig. 3-6), planning for future mine growth becomes important. The figure shows an example of how a multipair system may have grown in our hypothetical mine, which has four working sections (A, B, C, and D). In this example, when the system was installed, working section A did not exist, so three-pair cable was used to give sections B, C, and D private lines. (The telephone at the working face is an extension of the butt entry phone, which may not be reasonable in low coal.) When section A came into operation, either more cable had to be installed or more telephones had to be converted into extensions without private lines. Figure 3-6 shows that six-pair cable was run along the main haulageway, so that at this stage of development, several telephones were forced to share a pair.

Several telephones are extensions, and as long as that is a satisfactory condition, six-pair cable in the main haulageway is sufficient. However, if the objective is to provide every telephone with its own pair (which really is the point of a multipair dial access system), additional cables have to be run down the main haulageway. The lesson, of course, is to keep future needs in mind when planning cable layouts, particularly in areas like main haulageways and maintenance areas where telephone locations are unlikely to change for many years.

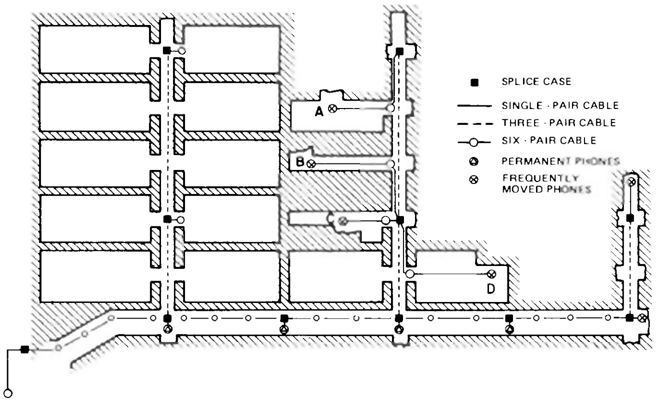

FIGURE 3-6. - Multipair installation.

Figure 3-7 shows details of the multipair system; once again, the three categories of telephones--permanent, semipermanent, and frequently moved telephones--can be seen.

3.3.3 Multiplexed Systems

Various types of multiplexed systems can also be implemented to satisfy communication requirements of permanent and semipermanent locations underground.

One system using multiplex equipment and a small PABX has been installed in a deep, multilevel, metal mine in the Western United States. This system utilized an existing twisted pair already strung through the mine to establish two seven-channel private communication links. A simplified diagram of the system is shown in figure 3-8.

The single twisted pair utilized by the systems extended from the surface, down shaft A to the 3,700-foot level, horizontally through a 5,000-foot-long

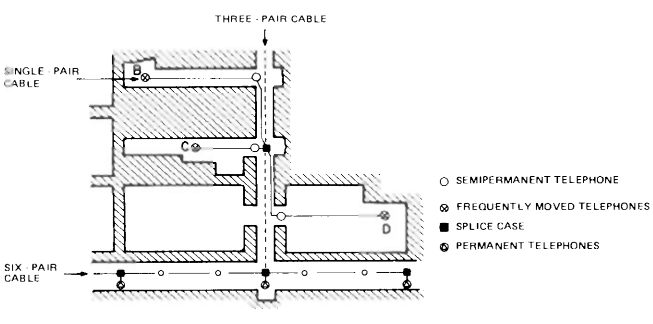

FIGURE 3-7. - Detail of multipair.

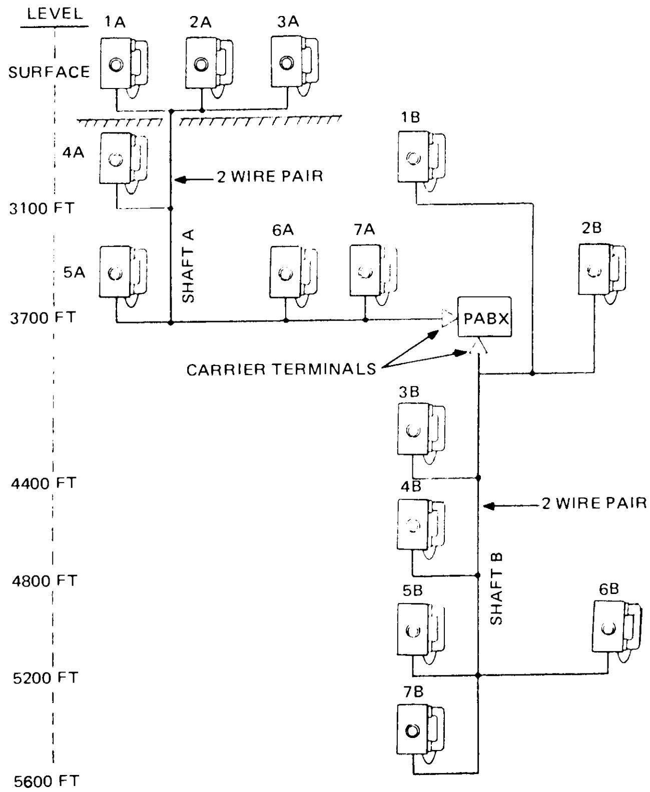

FIGURE 3-8. - Multiplex system with PABX.

drift to the underground headframe of shaft B, and then down shaft B to the 5,600-foot level. An air-conditioned room was available in the shaft B area at the 3,700-foot level that met all environmental requirements of commercially available PABX systems. Additionally, this location was approximately centered with respect to the physical locations of the desired phones. The single twisted pair was opened at this point, thereby forming two independent wire pairs (one running back to the surface, the other running down shaft B). A carrier system was then installed on each pair, and these two independent carrier systems were then connected to the PABX line circuits. This provided 14 private channels (1A through 7A and 1B through 7B) for communication within the mine. This system (described in more detail in appendix A), not being intrinsically safe, is not suitable for use in coal mines.

Presently, there is no intrinsically safe multiplexed telephone system designed for mine use that is commercially available. However, the Bureau of Mines is developing such a system. This system provides eight full duplex channels, some of which can be dedicated to monitor and control functions. The system uses inexpensive twisted shielded pair and is not under control of any central switching or control center. Because of this, the system will not be made inoperative because of a cable break or a central PABX failure. Other features include a message-leaving light on each phone, low-battery indicators, and compatibility with standard loudspeaking pager phone systems.

3.4 Mining Area

Safety regulations require that a communication link must be established within 500 feet of the working face. In coal mines a butt entry portable phone meets that requirement at the beginning of a panel's development, but a frequently moved section phone must be installed once the face has moved 500 feet from the butt entry phone. Weekly movement of the section phone might be necessary to keep the section foreman within range.

Under normal operating conditions the section foreman communicates by fixed phone to the shift foreman to request supplies and maintenance services, and to file his periodic productivity reports. Under emergency conditions he requests medical aid for personnel and reports hazardous conditions in his area. His primary concern is the safety and productivity of his crew.

The high acoustic noise level created by the mining machinery greatly reduces the effective communications between the foreman and his crew. This noise also interferes with the foreman receiving calls. Often a motorman must deliver a call-in message to the foreman when he is transferring haulage cars in his section. A standard procedure in some belt haulage mines is to turn off the conveyor system, thereby causing all the section foremen to call in. The working section crew primarily depends on the fixed pager phone system for direct communication with other parts of the mine.

Most existing mine communication systems stop at the last open crosscut of the section. Present mine communication systems are aimed at satisfying the need that the mine section foreman be able to communicate with the mine shift foreman. However, in some mines there may be additional communication needs within the mine section. Needs that are not adequately met include communications between the continuous miner operator and the shuttle buggy operators, between the shuttle buggy operators and the "gathering" locomotive operator, and between the general maintenance foreman and the section maintenance man repairing a machine. By satisfying these needs, both the safety and efficiency of mining operations can be improved. The existing power trailing cables to the face machine provide one means to achieve these communications capabilities in a reliable and economic manner. Another method of establishing voice communications between miners working at the face is by a radio system.

The operational and safety advantages of communication capabilities are several and diverse. The shuttle buggy operator will be able to alert the continuous mining machine operator of an impending roof fall. The shuttle buggy operators will be better able to coordinate their activities as they go in to dump on the belt or into the cars. The maintenance mechanic will be able to communicate with the surface while working at a face machine. When maintenance on a face machine is required, the maintenance mechanic can be called directly from the troubled machine.

3.4.1 Radio Systems

The use of two-way radios can result in better coordination of section activities, especially during the movement of mobile machines that must work in concert with each other at the face area. In many cases the operators cannot see one another, but with a system of communications they can still effectively work together. Safety will also be improved by better communication with isolated workers; for example, fan-hole drill operators in iron ore mines.

Improved management can be realized by means of effective section communication. The foreman can exercise better supervisory control, resulting in more efficient utilization of available personnel. Another benefit is the reduction of unnecessary travel, an extreme burden when mining low coal or on longwall sections. Repairmen, mechanics, and utilitymen can be quickly reached and dispatched to their place of need at the time of need. In spite of these advantages, two-way voice communication using portable radios is only now becoming practical for use in underground working sections. This has been due to the limited range that could be attained using the small handheld units.

Almost anyone who has ridden in an automobile is familiar with the radio fade that occurs when a car enters a tunnel. One might expect, then, that radio wave propagation would be very poor in mines, and it is still not feasible to design practical "wireless" portable radios capable of full mine coverage, except possibly for the smallest mines. However, both theory and experience show that the propagation characteristics of radio waves in mine tunnels improve as the frequency increases into the UHF band. This is attributable to a waveguide effect that is prominent when the wavelength of the radio wave becomes small compared with the cross-sectional dimensions of the tunnel. In the UHF band from 400 to 1,500 MHz, tunnel propagation is adequate to provide sectionwide radio coverage.

Probably the most important factor that determines the ability of UHF radio waves to propagate in underground mine tunnels is the cross-sectional dimension of the tunnels. In general, a high, wide opening favors better radio wave propagation. Figure 3-9 shows a comparison in the ability of 450-MHz UHF radio waves to propagate in high coal (7 feet) as opposed to low coal (3.5 feet), assuming a 16-foot-wide entry. The comparison also assumes that 2-watt UHF walkie-talkies are the source of signal. As indicated in figure 3-9, communication is possible for ranges up to 1,500 feet, along a straight entry in high coal, but the range drops to 400 feet in low coal. Of course the same principles apply to tunnels in noncoal mines.

Corners also present obstacles to the propagation of UHF radio waves. For a path that includes one corner, ranges are reduced but improve if one of the radios can be moved closer to the corner. However, propagation around a second corner is usually poor. To help offset this corner effect, it is good practice to transmit from intersections when possible, thus reducing the number of corners that have to be negotiated. Some other obstacles to radio wave propagation at ultrahigh frequencies are equipment such as shuttle cars and machines that reduce the cross-sectional area of the tunnels or entries. Table 3-1 shows that when shuttle cars are present, the range is typically reduced by 200 feet in high coal and by 50 feet in low coal.

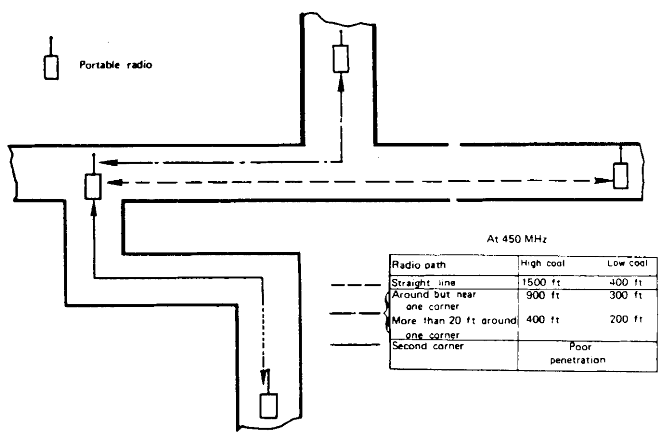

FIGURE 3-9. - UHF radio wave propagation in high and low coal.

TABLE 3-1. - Typical range reduction due to tunnel obstructions at 450 kHz

	High coal (7 by 16 ft)	Low coal (3-1/2 by 16 feet)
Shuttle car........ft..	200...................	50.
Bends..................	Moderate to severe....	Moderate to severe.
Permanent stoppings....	...do.................	Do.
Longwalls..........ft..	1,200.................	250.

The range of effective communication can be substantially increased by the use, and judicious placement, of a repeater, and in some applications, a radiating cable. When this is done, good communication can be established even under some of the worst conditions encountered on working sections. Referring to figure 3-10, suppose the two radios labeled A and B are out of direct radio range of each other. The repeater can function to bring the radios within range in the following manner. When radio A transmits on frequency F1, the signal is picked up by the repeater, which amplifies and converts it to a different frequency (F2) and retransmits it at a higher power level. Radio B receives the retransmitted signal. In this way, communications from radio A to radio B and B to A are established.

When the tunnels between the portable radios are heavily obstructed by machinery or metal roof-support structures, radiating (leaky coax) cable may also be installed in the tunnel to pick up and carry the signals to and from the repeater and portable radios. Figure 3-11 shows a sample cable installation for use with the repeater. In this case, the signals from radio A are picked up by the radiating cable itself, carried to the repeater, retransmitted as F2 signals onto the cable, carried along by the cable, and leaked into tunnels where they are received by radio B. The reverse occurs for transmission from B to A.

Even though a radio repeater such as shown in figure 3-10 can extend the operating range of radios A and B, this still provides only local coverage such as a working section. However, a radiating cable-repeater system such as shown in figure 3-11 can extend the operating range for many miles. The limiting factor in this case is the ability of a radio to transmit to and receive from the radiating cable.

The implementation of a UHF radio system for a mine working section can be approached from the standpoint of a basic

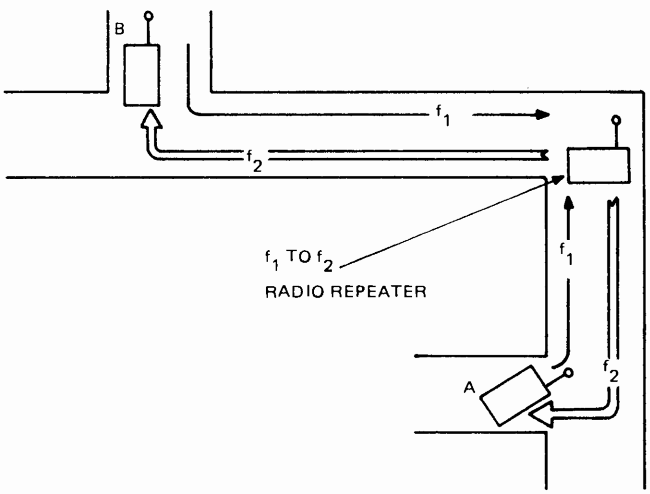

FIGURE 3-10. - Extending range with radio repeater.

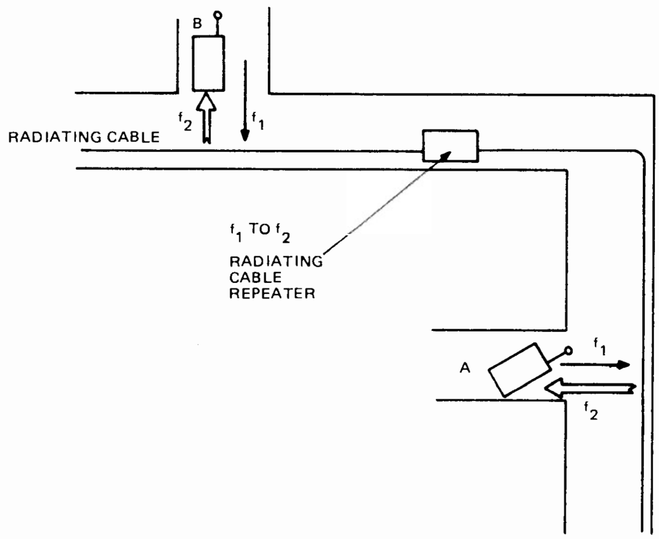

FIGURE 3-11. - Extending range with radiating cable.

"building block" philosophy as shown in figure 3-12. The fundamental building block is the UHF walkie-talkie radio itself. Several of these are sometimes all that is required for an effective sectionwide communication system. Usually, however, certain portable accessories are helpful to some miners; namely, speaker-microphone headsets, carrying vests, and remote handheld microphones.

In some situations, it may be necessary to extend the range of communications beyond that achievable when transmitting directly between portable units. This can be accomplished by adding a radio repeater to the system. A repeater, which can effectively double the area of coverage, is essentially a signal booster that receives weak signals from distant radios and retransmits them at full power. Further enhancement is possible by connecting the repeater to its antenna by means of a long length of special "radiating" cable that can be run through areas of poor coverage, such as the area along a longwall chockway. Radiating cable, also known as leaky coax or leaky feeder, allows signals to leak out of or into itself at a controlled rate. It effectively behaves as a long antenna that can guide radio waves around corners and bends.

For a more comprehensive system, an interconnect may be installed to interface the radio system with other communication systems, such as a pager phone or carrier phone system. This would be useful for paging key personnel in the section who are out of audible range of the section pager phone. However, the interconnect should operate only on a selective basis to avoid interference to, or by, the section radios. Hardware for implementing this radio interconnect is commercially available.

UHF section radio has been used successfully on room-and-pillar working sections at several mines. One such mine had a single conventional room-and-pillar section as shown in figure 3-13. The seam height was medium low (42 to 48 inches). The section radio system consisted of walkie-talkie radios carried by various miners and a radio repeater located at a communications center (known as the communication sled), which was placed near the power sled. The foreman, mechanic, shot firer, and a utility cleanup man were equipped with 2-watt radios operating on two channels, 454 and 457 MHz. The purpose of the repeater was twofold: (1) To extend coverage beyond the direct portable-to-portable range,

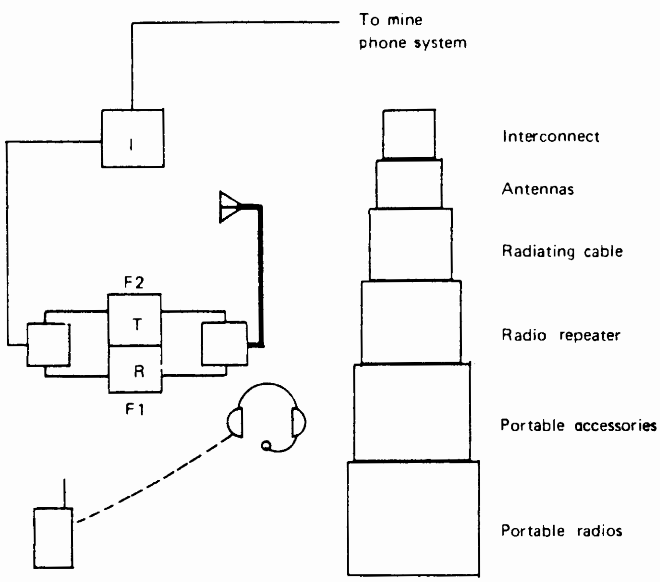

FIGURE 3-12. - UHF radio system "building blocks."

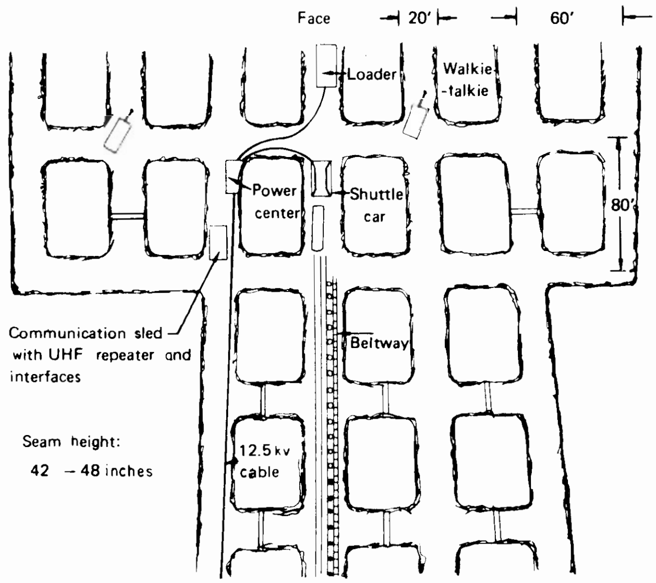

FIGURE 3-13. - Section layout of room-and-pillar section.

and (2) to provide an interconnect between the radio system and a system of carrier phones, which were mounted on mobile machines and interconnected by means of the trailing cable conductors to the machines. It was thus possible to communicate between roving miners equipped with radios and machine operators equipped with powerline carrier phones. Paging into the section radio system from a surface point was also possible via a surface-to-section carrier phone link and a special interface in the communication sled. A low-frequency through-the-earth radio link between the surface and communication sled was also provided, as shown in figure 3-14. At this mine the portable radios by themselves were usable over an area encompassing more than half of the working section. With the repeater, sectionwide radio coverage was possible.

A similar system was used at another room-and-pillar mine utilizing continuous mining machines. This section radio communication system also included machine-mounted carrier phones and a surface-to-section interface at a communication sled. Conditions at this mine were much more favorable for radio communication,

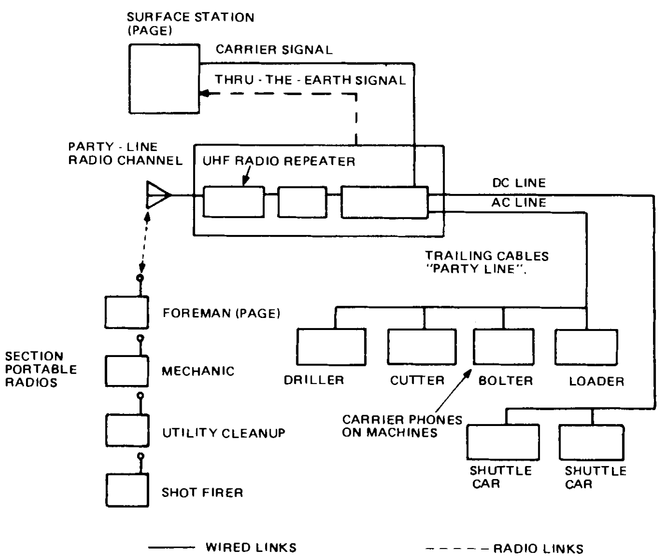

FIGURE 3-14. - Radio link between surface and communication sled.

mainly because the seam height was 6 to 7 feet. Direct portable-to-portable communication was generally good over an area encompassing up to three-quarters of the working section, although some dead zones were encountered where several corners had to be traversed. When the face was at maximum advance from the power center, the repeater located in the communication sled near the power center was out of reach of some portable radios; however, this could be rectified by extending the repeater antenna toward the face area by means of a coaxial cable.

3.4.2 Longwall Mining

With investment in a longwall face being in the millions of dollars, and production delays amounting to hundreds of dollars a minute, positive control and communication must be obtained. A representative longwall face crew might comprise a foreman, two shearer operators, three chock advance miners, one or two mechanics, a headgate operator, and one miner at the tailgate. Voice communication is frequently required between each of these crew members and between the headgate and tailgate. Since miners at the face must work under rather crowded conditions, starting and stopping the conveyor and mining machines are particularly crucial operations. It is essential that everyone on the face knows what is happening. During maintenance operations, frequent interchange of information between miners working at various points along the face is required. Good communication will improve the capability of describing and locating problems and coordinating maintenance efforts to reduce downtime.

Figure 3-15, a longwall installation in low coal, dramatically illustrates the limited working space in longwall mining. The area consists of a long lateral tunnel in which equipment may be easily damaged. Moreover, it is fatiguing to travel any appreciable distance to get to a phone placed along the face. Acoustic

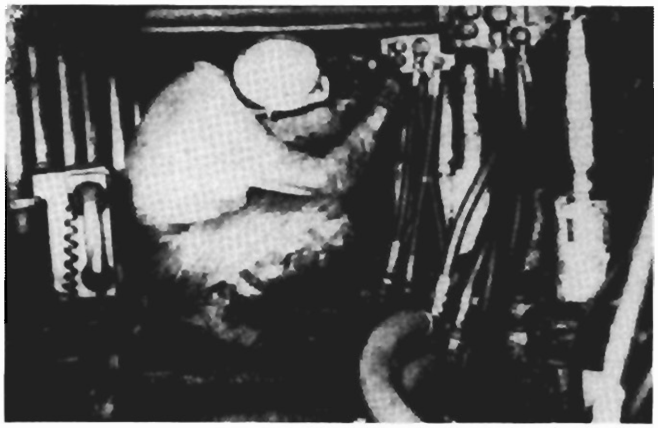

FIGURE 3-15. - Typical conditions encountered in longwall mining.

noise is also very high. Therefore, a communication system designed specifically for longwall mining applications should meet the following requirements:

1. Minimum size.

2. Rugged.

3. Direct acoustic sound along the face.

4. Rugged cable and connector design to survive in the harsh environment.

5. Sufficient power to permit operation along the maximum length of the longwall.

6. Certain control and signaling features that can be incorporated into the phone system.

U.S. longwall faces commonly use standard U.S. pager phones as a means of implementing interface communication. However, these systems do not provide an adequate face communication system. Major problems are as follows:

1. The phones and cables are easily damaged owing to the close quarters and severe environment.

2. Miners on the face may have to travel 50 to 100 feet to use phones; sometimes phones can survive only at the headgate or tailgate, which is marginally acceptable on a short face, say 250 feet, but unsatisfactory on faces as long as 400 feet; in contrast, phones are placed 40 to 50 feet apart in West Germany.

3. The conveyor creates a high-noise environment, and shearer noise often makes it impossible for shearer operators to hear a page.

4. Communication is required laterally along the face, and U.S. pager phones have not been designed with this in mind.

Several European systems, however, are available that have been specifically designed for longwall applications. Figure 3-16 shows one type of phone, which has already been installed in a few U.S. longwalls and is reportedly well accepted. Figure 3-17 shows the main control unit, which is installed at the headgate. Some of the features of European longwall pager phone systems are pull-wire signaling, machinery lockout buttons, prestart warning, fault detectors (in some cases) which stop the machinery, blast-proof design, and a central power supply at the headgate with standby batteries in the individual phone units.

For the potential U.S. user, there are, of course, problems associated with this equipment. The first is expense. A 10-phone system incorporating all the desired features may cost around $25,000. A 10-phone system with voice-only capabilities might cost only about $6,000 to $7,000, but this is still at least twice

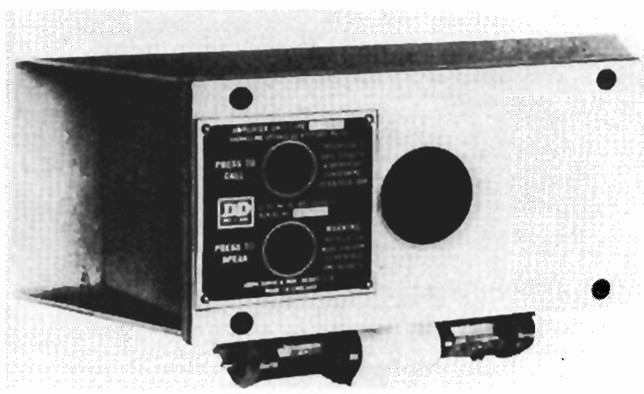

FIGURE 3-16. - Longwall phone.

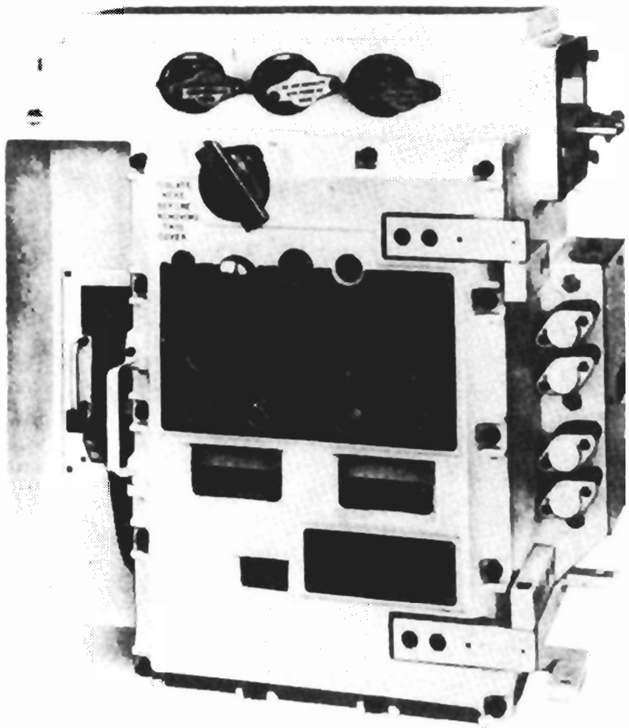

FIGURE 3-17. - Main control unit.

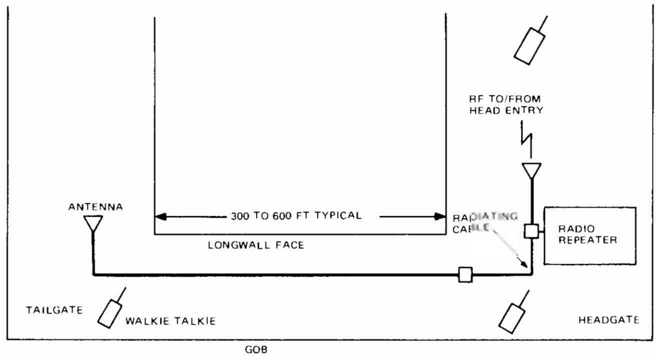

FIGURE 3-18. - Repeater-based UHF radio system layout for longwalls.

as much as a U.S. pager phone system. Secondly, there are a limited number of suppliers. Thirdly, a mine may have to either carry its own inventory or expect long lead times in getting spare parts. Finally, in-house maintenance skills have to be developed. However, given the high cost of a longwall system ($1 to $2 million), a proper understanding of the value of a good phone system in reducing downtime indicates that these systems are still worth considering.

With any system, certain individuals should be able to communicate from any location along the chockway without the fatiguing ordeal of crawling to a phone. This requirement cannot be totally met by any wired phone system, and with some exceptions wireless radio for longwalls is not feasible at ultrahigh frequencies. Table 3-2 summarizes the important points regarding the design and implementation of a longwall UHF radio system. However, cable-aided UHF radio is feasible and may be another choice for obtaining the linear tunnel coverage required on a longwall section.

On shorter faces, a radiating cable extending along the length of the longwall and passively terminated at each end with a suitable antenna can provide face coverage without a repeater. A radio repeater, connected to the cable at one end, may be needed on longer faces, or when coverage to the head entry outby the headgate is required. A repeater-based configuration for a longwall UHF radio system is shown in figure 3-18. In this system, good radio coverage can be expected along the face area and into the head entry for several hundred feet. If the repeater should fail, direct communication between portable radios is still possible at reduced range. This system can be implemented using commercially available battery-operated hardware that is also MSHA approved (fig. 3-19).

TABLE 3-2. - Ranges of completely wireless communication system for longwalls at 450 MHz

Type of roof support	Range with no machine, ft		Range with shearer machine, ft	
	High coal	Low coal	High coal	Low coal
Chocks......	300	150	100	50
Shield......	1,000	150	300	50

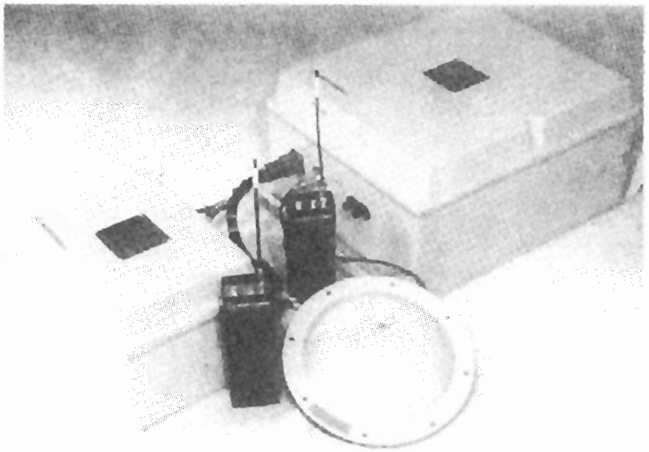

FIGURE 3-19. - MSHA-approved UHF repeater and battery unit, with "hardhat" antenna and portable radios.

3.5 Haulageways

Operators of vehicles in underground haulageways must be able to communicate with one another and with other areas in the mine to improve safety and increase production.

The type of systems that can be implemented to meet the communication requirements of underground haulageways depends upon the method of haulage itself. From the standpoint of communications, haulage systems can be considered as either trolley or nontrolley.

Trolley haulage, as used in this manual, means vehicles that are tracked (ride on rails) and are electrically powered from an overhead trolley wire. In mines using this type of haulage, a carrier phone system using the trolley wire is almost always used to satisfy the communication requirements. The trolley wire and tracks serve as the carrier current path. Methods, techniques, and ways of improving carrier phone systems are given in section 3.5.1. Special control, monitoring, and communications requirements involved when moving off-track equipment under an energized trolley wire are described in paragraph 4.4.3d of chapter 4.

All other forms of haulage systems are grouped into the nontrolley category. The reason for this is because the solutions to the communication requirements in these systems are similar. Nontrolley haulage systems include the following:

Rail vehicles with self-contained power sources (battery or diesel powered).

All rubber-tired vehicles.

Communication systems applicable to nontrolley haulage systems are described in section 3.5.2.

3.5.1 Trolley Haulage

As previously mentioned, carrier phones are usually used to satisfy the communication requirements in haulageways where rail vehicles that draw power from an overhead trolley wire are used. One reason carrier phones have become so popular is that they operate over the existing trolley wire dc power circuits to provide two-way voice communication between the tracked vehicles and with fixed stations in the mine. No additional wires or cables must be installed in the mine. In underground mining, these carrier systems are used extensively for traffic control of the tracked haulage equipment and personnel carriers. These phones are FM push-to-talk transmitter-receiver units designed for common talk (party line) operation.

Carrier frequency couplers consisting of bypass capacitors are used to provide continuity of the RF signal path between sections of trolley served by different dc power centers. These carrier systems typically operate in the 60- to 200-kHz range. (See section 2.4 for basic theory of operation of carrier current phone systems.)

The carrier phone located on each tracked vehicle is primarily used for control of vehicle traffic. All vehicles are kept in communication with each other and the dispatcher over the single-channel (party line) carrier phone system. This single-channel network keeps the dispatcher and all motormen in continuous contact with one another so that right-of-way and the disposition of haulage cars will be known to all. One inherent advantage of the trolley carrier phone system is that it is a party line system. In certain applications, this would be a disadvantage since private communication channels are not available. For haulageway traffic control, however, it is beneficial if each motorman does hear conversations between other motormen and the dispatcher. This phone system also allows the dispatcher to notify all motormen of any mine emergency. The two drawbacks to this system follow:

Trolley wire power failures, which cause the carrier communication system to go dead unless backup batteries are installed.

Dead zones, which are sections of track where the phone is inoperative due to excess electrical noise, excess attenuation of signal strength, or standing wave effects.

The first drawback, loss of communication due to power outage, can be corrected by the use of backup batteries in each vehicle (required by law if the carrier current system is the only communication system in the mine). The backup batteries would normally be trickle-charged to full capacity and then maintained at full charge. In the event of a power failure on the trolley wire, the backup batteries would automatically power the carrier phones and allow for voice communications for many hours. Because the haulage system is vital to mine operations, extended power outages on the trolley line are not tolerated. Any trolley power failure is immediately recognized and corrected as soon as possible. Thus, communication outages due to power failures are minimal.

The second problem associated with some carrier phone systems is that of "dead zones." There are areas where two-way communication between a vehicle and a dispatcher or between vehicles is not possible. Dead zones are caused by extreme attenuation of signals, excess noise, standing waves, and/or inadequate squelch control. The most significant of these causes is the extreme attenuation of the carrier phone signals on the trolley wire-rail. The trolley wire-rail is a poor radio frequency transmission line for several reasons, the most dominant of which is the presence of many bridging loads between the trolley wire and rail. Branches and the lack of good electrical terminations contribute to the problem as well. The bridging loads, which both absorb and reflect power, comprise such items as personnel heaters, rectifiers, pumps, haulage vehicles (motors), locomotive and jeep lights, insulators, signal and illumination lights, and even the carrier phones themselves.

Because of the importance of good communications in the haulageways and because a large number of mines use carrier phones to meet these requirements, many programs have been sponsored to improve trolley carrier phone systems.

One program was designed to (1) identify poor performance of trolley carrier phone systems, (2) assess the causes of poor performance and classify them on the basis of equipment, coupling, or transmission problems, and (3) propose and verify the means to overcome these problems.

Figure 3-20 illustrates the signal-attenuation rate for an "unloaded" trolley wire-rail transmission line; a band of rates is shown because the actual rate depends on the conductivity of the surrounding medium. If an attenuation rate of 1 dB/km is used, a trolley carrier phone line having an allowable transmission loss of 70 dB (from 25 volts to 8 millivolts) yields a communication range of 70 km (43 miles). This performance, in the absence of bridging loads, can be compared with that of a sample trolley wire-rail loaded as illustrated in figure 3-21. Here, just three bridging loads of modest value (typical of vehicles and personnel heaters) reduce the signal 55 dB over a distance of just 4,500 feet. The figure also shows the signal level that would exist over the same distance on a properly terminated

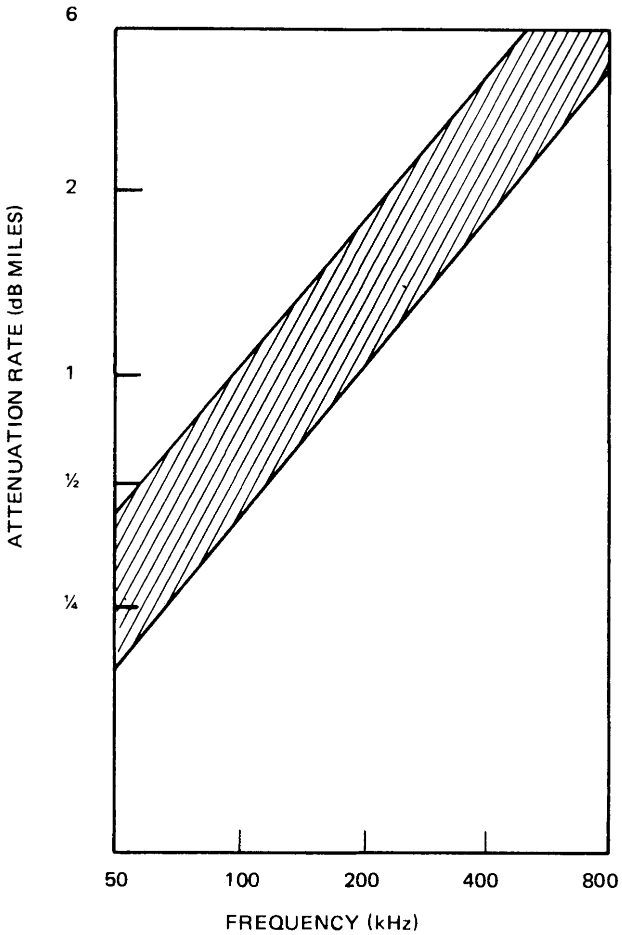

FIGURE 3-20. - Signal-attenuation rate for an "unloaded" trolley wire-rail transmission line.

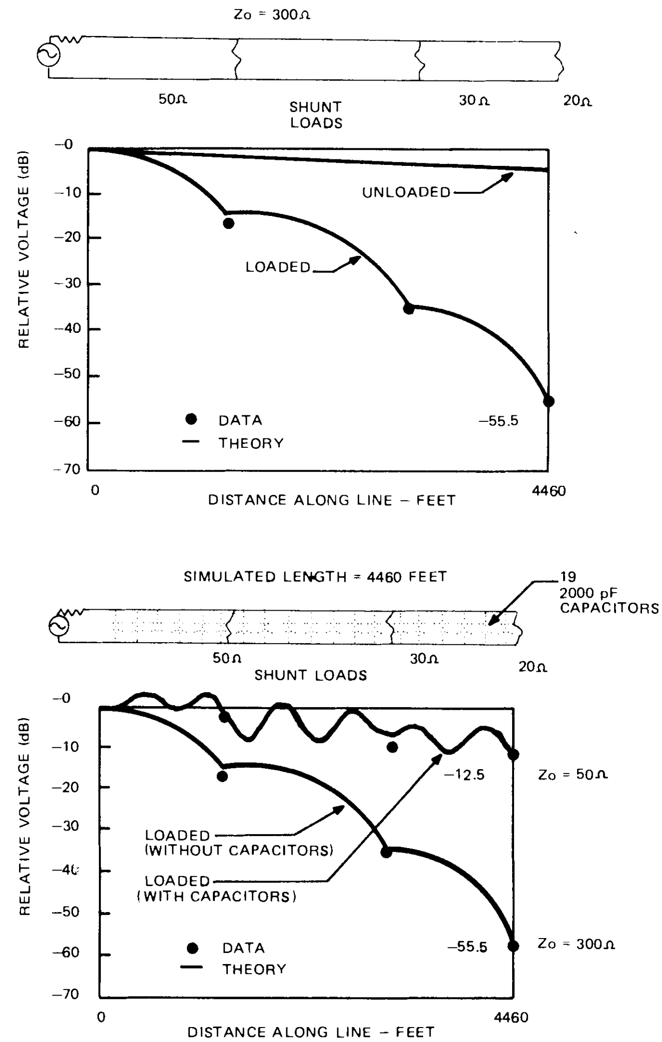

FIGURE 3-21. - Signal level on simulated trolley wire-rail.

trolley wire-rail without bridging loads. With such signal reductions, it is easy to see why it is difficult to obtain long-range transmission of carrier signals using the trolley wire.

There is one approach that appears to have merit in overcoming the exceptionally high attenuation rates that can be expected on the trolley wire-rail--the dedicated wire technique.

3.5.1a Dedicated Wire

The best approach to overcoming the extremely high attenuation rates imposed by bridging loads is a single-purpose, or "dedicated," wire. The characteristics of an unloaded trolley wire-rail are such that it forms a low-loss transmission line. Therefore, a separate wire strung in an entryway, with the same rail return path as the trolley wire but unloaded by any bridging loads, would similarly serve as a low-loss line. Such a configuration forms a three-wire transmission line.

Studies have shown that the primary mode of propagation for such a configuration is a low-loss mode supported by the dedicated wire, with the rails serving as the return signal path. The signal improvements that can be expected from such a configuration are illustrated in figure 3-22, which shows the voltage signal strength versus the distance along a heavily loaded trolley wire-rail with a parallel dedicated wire.

Four separate conditions of transmission and reception are shown in

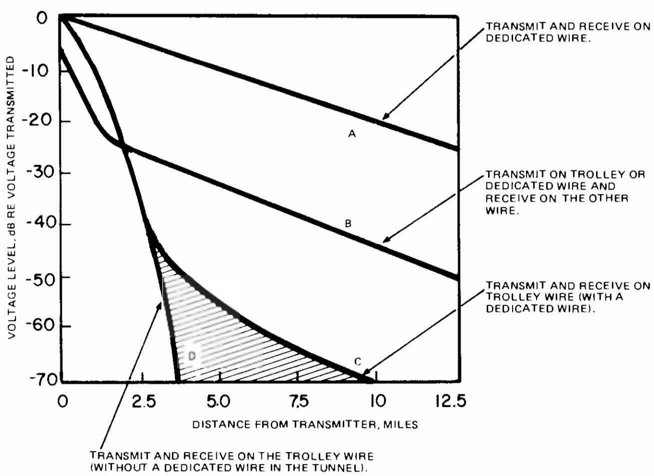

FIGURE 3-22. - Voltage signal strength versus distance along heavily loaded trolley wire-rail with a parallel dedicated wire.

figure 3-22. For example, if the dispatcher transmits on the dedicated wire and the motor operators receive on the trolley wire, then the dispatcher's transmission will produce a curve of trolley signal level versus distance like curve B. At a distance of approximately 12.5 miles the dispatcher's signal shows only a loss of 50 dB. The remaining signal level is entirely adequate for operation of the carrier phones, since the allowable transmission loss is about 70 dB.

The crosshatched area between curves *C* and *D* illustrates the improvement that can be obtained when both the dispatcher and motor operators still transmit and receive on the trolley wire but when a dedicated wire has been installed along the haulageway.

Curve *A* shows the signal loss between fixed base stations, both of which can transmit and receive over the dedicated wire.

The dedicated wire is installed with no direct connection to the trolley wire-rail; however, a strong electromagnetic coupling exists between the dedicated wire-rail and the trolley wire-rail, simply because of their physical proximity. Thus, the dedicated wire is not jeopardized by direct coupling to the high-voltage trolley wire and is not influenced by its loads.

Tests indicate that excellent results can be obtained with a dedicated wire. The dedicated-wire concept permits installation of a transmission line with controlled branching that can be terminated to avoid standing-wave patterns. The price paid is that the wire has to be installed and maintained in a haulageway.

A recent study (<u>26</u>)[1] recommends that the dedicated-wire method is usually the most effective and practical way of upgrading trolley carrier phone systems.

Another research program provided a set of five guidelines for operating personnel to improve their carrier phone systems. These guidelines give detailed instructions for installing trolley carrier phone equipment onboard mine vehicles and at the dispatcher's room, converting a rail haulage trolley wire-rail and feeder system into a functional carrier-frequency-transmission line, checking the performance of the trolley carrier phone system, and using portable test equipment to aid in system maintenance. A detailed description of the conclusions and the recommendations set forth in these guidelines are presented in chapter 6 of this manual.

Rather than offering detailed comments on the contents of each of these guidelines here, we focus on just one aspect of the guideline concerned with converting the trolley wire-rail into an efficient transmission line. In the preceding discussion on the causes of poor performance, the extremely poor propagation characteristic of the trolley wire-rail was cited. Apparently, this poor propagation dominates in determining the performance of trolley carrier phone systems. Thus, it is appropriate that serious consideration be given to determining the signal and noise levels on each trolley wire system. Signal strength and

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[1]Underlined numbers in parentheses refer to items in the bibliography at the end of this chapter.

electromagnetic noise level measurements should be made at points along the trolley and noted on a mine map. The procedure is simple. The dispatcher's transmitter is used as the signal source, and both the strength of the signal along the haulageway and the corresponding noise level are measured. This measurement is conveniently made by equipping a jeep with a tuned voltmeter. The jeep moves along the haulageway, stopping at intervals of about 2,000 feet. The operator calls the dispatcher and asks for a 10-second keying-on of his transmitter. The received voltage on the tuned voltmeter is noted on a mine map, and the noise level is also noted. This map then identifies regions of the mine where excess noise may be the problem, as well as regions where weak signal levels cause problems. The map also aids in identifying the key bridging loads branches, or unterminated lines that can cause problems. This signal- and noise-mapping process is the key to identifying the major causes of poor signal reception in a particular mine.

Once the probable source of difficulty has been identified, the remaining part of the guidelines can be consulted to determine possible ways of treating the problem. For example, if a rectifier is affecting signal propagation, the guidelines provide three different ways to treat the rectifier to reduce the problem.

3.5.1b Summary

Communications with moving tracked vehicles in a rail haulage mine pose a difficult problem. These communications take place from dispatcher to vehicles or from vehicle to vehicle via the trolley line, which is a very poor communications line. As a result, dead spots and high-noise areas can occur anywhere along the line; also, signal strength can decrease simply as a function of distance.

Although trolley carrier phone systems leave much to be desired for haulageway communications, the fact remains that they do represent one practical means of dispatcher-vehicular communications. Most problems associated with these systems are transmission line related; a trolley line was never intended to be a good communications line, and it certainly is not. However, techniques do exist for improving overall communications. These techniques can be easily implemented, and the results are often excellent.

3.5.2 Nontrolley Haulage

An increasing number of both newly developed and older mines have been abandoning tracked trolley vehicles and are conducting their haulage, maintenance, and personnel transport operations with other types of vehicles. Obviously, communications to and from vehicles operating independently of a trolley wire cannot be implemented by the trolley carrier phones discussed in the previous section.

Communication systems required for battery- or diesel-powered rail vehicles or rubber-tired vehicles have one common characteristic. Because these vehicles are not physically attached or connected to any wiring or other conductor in the mine, some form of radio link must be utilized to establish the final voice link with the vehicle. If voice communication exists from a nontrolley vehicle, then an antenna-radio link of some form must be used to replace the direct connection provided by the trolley wire.

Several methods exist for providing communication between nontrolley mining vehicles. Studies have been conducted of high-frequency systems utilizing the so-called leaky-coax cable to carry signals throughout a mine. Other studies in the wireless radio area have shown that at medium frequencies, signals follow the existing mine wiring for great distances.

3.5.2a Leaky-Coax Systems

A leaky coax is a special type of coaxial cable that allows radio frequency signals to leak into and out of itself. With this type of cable, signals can be transmitted to and received from mobile radio units near the cable. Leaky coax is therefore ideally suited for haulage applications. In effect, the cable guides the radio signals down the tunnel (fig. 3-23). Although signal strength does attenuate along a cable run, repeaters or in-line amplifiers can be used to extend the range of coverage. Several techniques have been used:

1. Borrowing from conventional mobile radio communications practice, individual fixed-base stations can be installed at intervals as necessary to provide the total range, all stations being under a common remote control with the first. Such a system has been in use at a British mine since 1970.

2. A series of one-way in-line repeaters, such as the daisy-chain system shown in figure 3-24, is effective; it does have a slight disadvantage in that an audio return line is required and, when branches are required, the system can become complex.

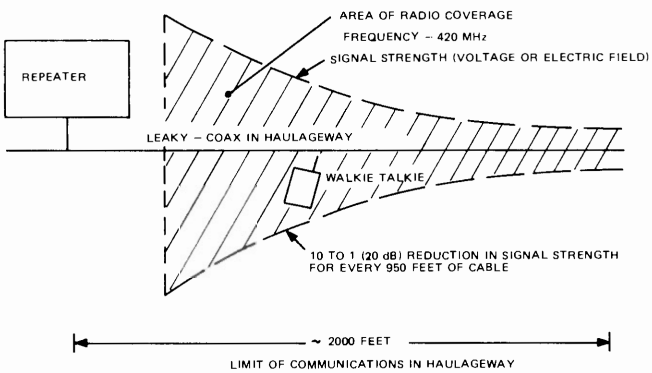

FIGURE 3-23. - Cable "guiding" radio signal down a tunnel.

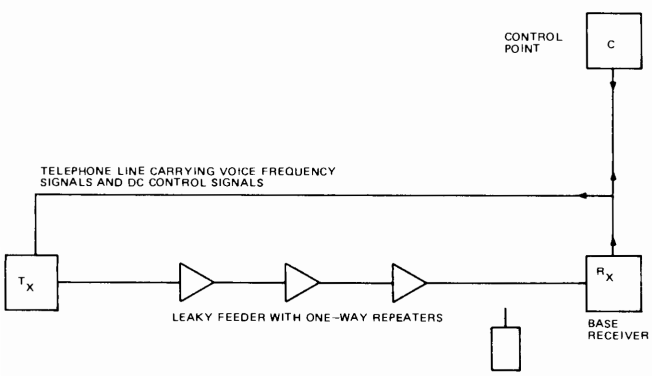

FIGURE 3-24. - Block diagram of a daisy-chain repeater system.

3. Multiple-frequency repeater schemes (fig. 3-25) have also been used successfully; the simplest uses one transmitter and one receiver.

Communication benefits of a leaky-coax system are typified by one system developed for an iron ore mine (block-caving operation) using rubber-tired, diesel-powered vehicles. The system chosen to satisfy the communication requirements at this mine consisted of a UHF leaky-coax system. Figure 3-26 is a simplified diagram of the system.

In addition to providing communication to personnel carriers, maintenance and production vehicles, and the ambulance (fig. 3-27), the system provides communications for roving miners, foremen, fan-hole-drill operators, and supervisors. Communication requirements were satisfied by using (1) UHF wireless radio, (2) a radiating coaxial cable or "leaky" transmission line to carry the signal throughout the haulage and subdrifts of the mine, (3) interconnected VHF and UHF repeaters, (4) portable transceivers, and (5) vehicle-mounted transceivers.

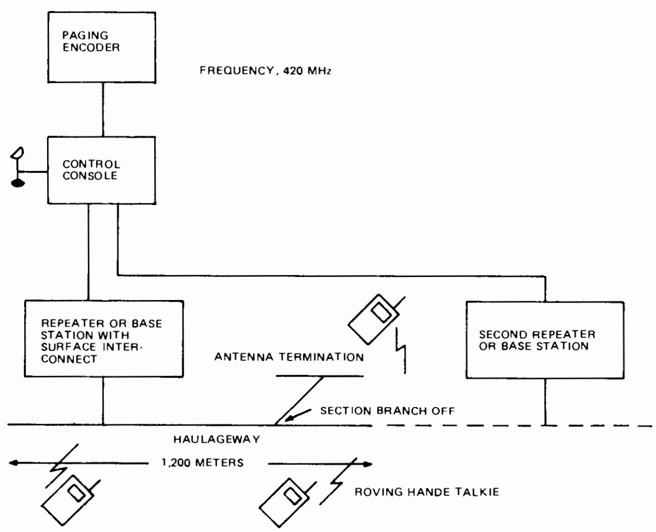

FIGURE 3-25. - Two-frequency repeater concept.

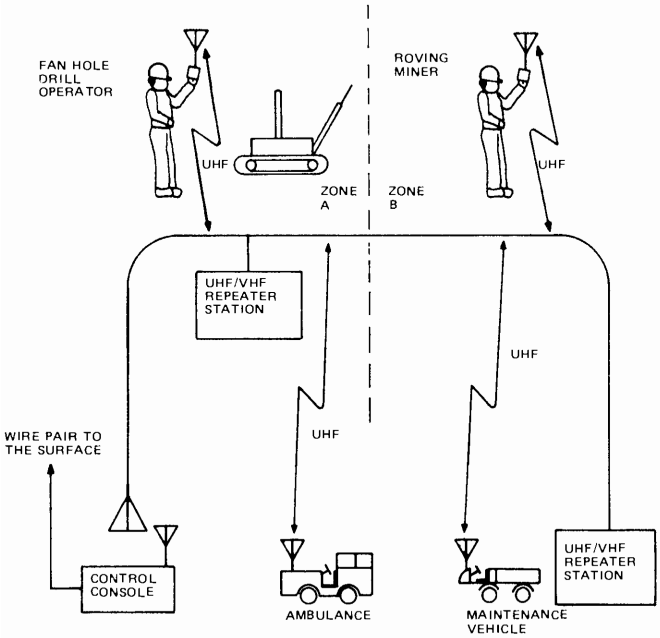

FIGURE 3-26. - RF leaky-coax communication system.

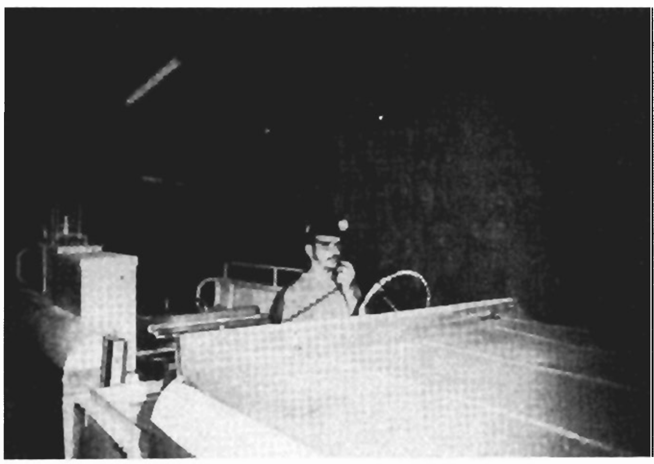

FIGURE 3-27. - UHF mobile radio mounted on underground ambulance.

The mine was divided into two RF regions, with each region (zone) containing one UHF-VHF repeater station and associated runs of leaky coax. The system of cables effectively wires the mine for UHF signals between portable and mobile units. Each repeater station can receive and transmit signals on the cable at both UHF and VHF. VHF signals are used on the cable as a communication link between the stations, while the UHF is used for the communication link to and from the portable and mobile units. The two UHF repeaters transmit on F2 and receive on F1 as shown in figure 3-28. The VHF repeaters use frequencies F3 and F4 to interconnect the two UHF zones. Each UHF-VHF repeater station can simultaneously transmit and receive on both UHF and VHF.

The mobile radios transmit on F1 and receive on F2. All information therefore goes to the repeaters, then back to all other units. The portable radios are also capable of transmitting on F2 and therefore are able to talk to one another without the repeaters on a local simplex basis. Audio control lines are provided from the crusher console to repeater station A and from the surface guardhouse to the shaft bottom station, thus providing system access from two hardwired locations as well as an important emergency link to the surface.

As an example, suppose that a mobile radio in zone A wants to talk to a roving miner equipped with a portable radio in zone B. The operator in zone A keys his radio and talks into his microphone to transmit his message on UHF F1. The UHF signal is coupled to the leaky coax and travels to the UHF-VHF repeater in zone A. Repeater A rebroadcasts the message back to zone A on UHF F2 and also sends the message to the repeater in zone B on VHF F4. This signal travels on the coaxial cable to UHF-VHF repeater B where it is picked up by the VHF receiver. The signal is then converted to UHF F2 and routed onto the leaky coax for distribution in zone B.

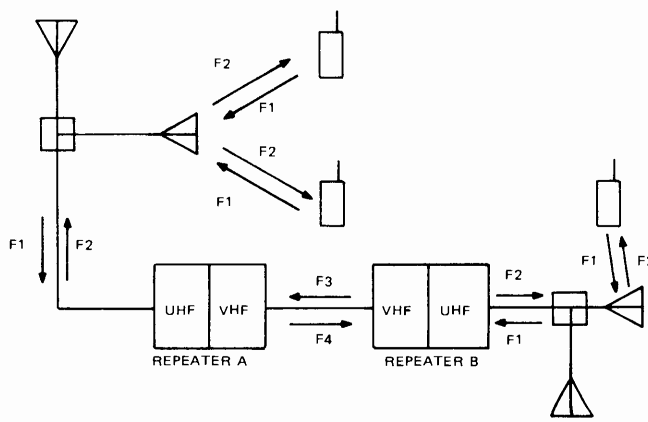

FIGURE 3-28. - UHF-VHF repeater system.

For this type of installation, specifications recommended that the cable be supported every 5 feet. To avoid installing a large number of anchors in the rocks, a 3/16-inch steel messenger wire was attached at 20-foot intervals to roof-bolt-supported T-bars (fig. 3-29). The cable was then strapped to the messenger wire with standard cable ties.

A vehicle-mounted work platform, which could be mechanically raised or lowered and which was equipped with a frame for supporting cable reels, facilitated cable installation. The factory cut the cable to predetermined lengths, installed connectors, and tagged the cable with location identifiers. In mine areas that were so far removed from the main cable that radio transmissions could not be established, a stub cable was installed with one end connected through a power divider to the main cable and the other end terminated with an antenna.

3.5.2b UHF Reflective Techniques in Underground Mines.

UHF radio (300 mHz to 3 gHz) is the only way of achieving true radio propagation in an underground mine. Propagation is possible because the mine entries function as waveguides that confine the transmitted energy. Several thousand feet of range, line-of-sight, is often possible without leaky feeder cables if the entries are large enough.

FIGURE 3-29. - Radiax cable installation on messenger wire.

However, the nature of UHF is such that propagation around bends and corners introduces tremendous signal losses. In this regard, it is similar to the transmission of light and, like light, it can be reflected by flat metallic surfaces. These characteristics of UHF make possible a whole-mine communication system that does not rely on leaky feeder cables. The Bureau of Mines evaluated such a system in an underground limestone mine that had large dimension haulageways. A UHF reflective radio system was designed to allow communication between supervisory personnel, maintenance personnel, haulage operators, and surface operations. Communication was also provided between the hoist operator and slope car occupants. A closed circuit television (CCTV) system allowed continuous, remote visual monitoring of critical belt transfer points and underground dust disposal operations.

The Black River Mine was selected as a typical metal-nonmetal room and pillar mine. It is nearly 4,000 feet in diameter, 650 feet deep, and has essentially straight crosscuts approximately 30 feet wide and 24 to 40 feet high with pillars approximately 35 feet square. Entry is through a 2,200-foot slope by means of a single drum, hoist-powered flat car and enclosed man carrier. Rubber tired, diesel powered mine vehicles travel along designated haulage and travel roads from the active faces on the mine's perimeter to two rock crushers, the shop area, and the base of the slope.

Tests of communication between handheld, 2-watt UHF transceivers in the room and pillar limestone mine were satisfactory for approximately 2,000 feet through straight haulageways but the range of communication at right angles to haulageways into intersecting crosscuts was quite limited. It was evident that the radiation from the transceivers was not being reflected by the limestone pillars into the intersecting crosscuts.

To improve communication in intersecting haulage roads, 27 passive reflectors were designed and installed at major intersections. The reflectors were formed from 4- by 8-foot sheets of No. 16 gage soft aluminum sheet that were suspended from wires attached to roof plates and bolt anchors. The roof height was sufficient to allow haulage vehicle clearance at each installation. Two distributed antenna systems were designed to provide either an antenna or reflector at the intersection of principal haulage and travel roads. Each antenna system consisted of approximately 1,200 feet of 7/8-inch low loss foam dielectric transmission line which fed, through 2:1 power dividers, four 5-dB gain mobile whip antennas that were suspended at intersections.

A leaky coaxial cable anatenna system along the principal haulage and travel roads was considered but rejected because the range of communication at right angles to the leaky cable into intersecting crosscuts would have been much less than the range of communication from antennas. The leaky cable system is appropriate for long tunnels but not for intersecting roads in a room and pillar geometry. Also, a leaky cable would be more expensive.

One central, or "backbone" coaxial cable carried 60 Hz power, radio signals, and CCTV signals for the entire system. Redundant routing of the backbone cable insured continued system operation in the event of a cable break.

Fourteen 11-watt mobile radios equipped with automatic identification and emergency alarm encoders were installed on vehicles in the mine. The encoders are used on mine haulage trucks to automatically send three status signals; truck bed up (dumping), truck bed down, and hot engine. This information is displayed by number codes along with the truck's identification number on display units in the engineering office above ground and the mine foreman's office underground. A record of all calls, status, and alarm messages is automatically printed in the engineering office.

Fifteen 2-watt portable transceivers equipped with automatic identification and emergency alarm encoders are used by mine department heads, foremen, and personnel in the mine.

Signal margin measurements of the base-repeater station signals along haulage and travel roads were made after both distributed antenna systems had been completed, which demonstrated that approximately 75% of the mine area received satisfactory signals, but active mining areas along the perimeter of the mine were not adequately served. The distributed antenna system would have to be extended to serve additional antennas near the mine faces. However, the cable attenuation would drastically reduce the power radiated from the antennas and the signals received from the mobiles and portables so that very little improvement would be realized. Additional base-repeater stations were considered; however, the added complexity and cost of multiplexing equipment and for extending the backbone cable control system stimulated the development of a low-cost, two-way multichannel signal booster system. A prototype signal booster was constructed and tested. Six amplifier signal boosters, 10,000 feet of cable, and 16 additional antennas were installed in the mine. Subsequent signal measurements showed adequate coverage of all desired areas.

3.5.2c Dedicated-Wire Radio Systems

It is possible to use trolley carrier current techniques and hardware to communicate with vehicles that do not use a trolley line, such as battery-powered railed or rubber-tired vehicles. However, in this case, a "dedicated wire" is essential for proper operation. Such a system is shown in figure 3-30.

The dedicated wire takes the place of the trolley line. However, since the carrier phone on the jeep communicates with the dedicated wire by a loop antenna, instead of touching it like it

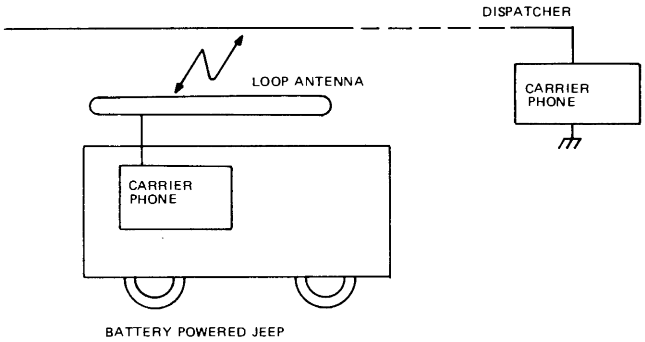

FIGURE 3-30. - Dedicated-wire radio system.

would a trolley line, this system is relatively inefficient. In general, it is usually necessary for the loop antenna to be rather close to the dedicated wire for communications. This problem is caused in part by the fact that carrier phones were never intended to use antennas, and cannot operate at high enough frequencies to make this approach efficient.

However, research has shown that such a system operates well if medium frequencies are used. These frequencies, usually around 500 to 900 kHz (as opposed to 100 kHz typical of trolley carrier phones) can operate with loop antennas very efficiently. Considerable research is being done by industry and the Bureau of Mines to develop whole-mine medium-frequency systems.

3.5.2d Wireless Radio System

An obvious advantage of any true radio system is that the system requires no transmission lines or cables. These systems are immune to communication outages caused by line breaks due to roof falls or damage from machinery. However, the underground mining industry cannot take for granted the utilization of wireless communications as can their counterparts on the surface. As an example, at CB radio frequencies, reliable communication in a mine entry is limited to about 100 feet. Two options are available to the underground mine operator: (1) To use frequencies that are high enough to utilize the entries as waveguides, or (2) to use frequencies that are low enough that propagation through the earth, or by parasitic coupling, can be insured. Before discussing the advantages and disadvantages of each technique, the subject of radio interference and signal attenuation in underground mines must be considered.

3.5.2d.i Interference

During normal operation, the machinery used underground creates a wide range of many types of intense electromagnetic interference (EMI), which is a major limiting factor in the range of a radio communication system. EMI generated in mines is generally a random process. Therefore, the most meaningful parameters for EMI are statistical ones. In work by the National Bureau of Standards, time and amplitude statistics have been used in order to unravel the complexities of EMI noise in mines. Without going into the details of data collection techniques or advanced statistical analysis, we will summarize the findings and conclusions on EMI affecting haulageway radio communications. Figure 3-31 shows interference levels measured along haulageways in four different mines.

The EMI noise levels shown for mine 1 are based on measurements made in a mine located in southwestern Pennsylvania. Room-and-pillar techniques were used with mining accomplished using a continuous miner, shuttle cars, and electric trolley rail haulage.

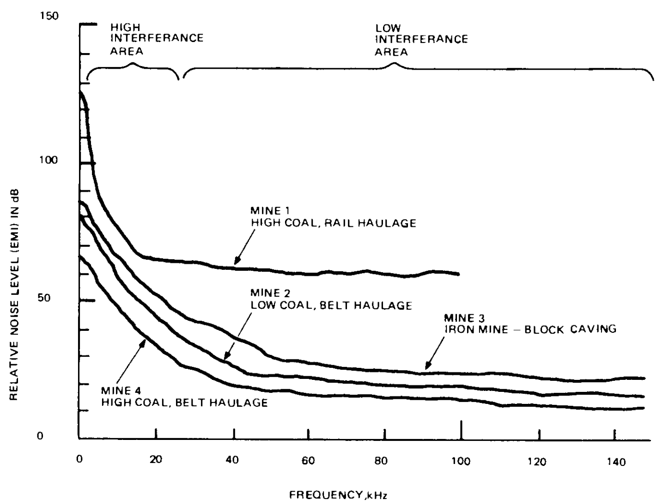

FIGURE 3-31. - Interference levels measured along haulageways in four mines.

The majority of noise measurements were made in an area where the overburden ranged from 600 to 900 feet. The entire mine, including all machinery, is powered by 600 volts dc. All conversion from alternating to direct current is done on the surface, with the result that no ac power is brought into this mine.

The EMI noise levels shown for mine 2 are based on measurements made in West Virginia. The coal in this mine occurs in a narrow seam, approximately 3 feet thick, and is called low coal. The measurements were made in the two sections of the mine using the longwall mining technique where overburden was between approximately 900 and 1,500 feet. The mine also had seven conventional room-and-pillar sections. This mine used 250-volt dc trolley haulage to carry coal out of the mine, and ac-powered conveyor belt haulage from the section to the trolley. All of the section longwall mining equipment was ac powered, with the exception of a dc-powered cable winch which was used occasionally to advance portions of the longwall equipment. The face and associated longwall equipment were 450 feet long. There were a total of six electric motors in the section ranging from 15 to 300 hp. The shear and face conveyor were powered by 950 volts, and the stage loader and hydraulic pumps operated from 550 volts. The stepdown transformer supplying these voltages was kept approximately 150 to 700 feet back from the face and was supplied with 13,200 volts.

The EMI noise levels shown for mine 3 are based on measurements made in a Pennsylvania iron mine. The level where measurements were taken was approximately 2,300 feet below the surface. The ore body is a large, flat, oval deposit about 300 feet thick, mined by undercutting and allowing the ore to cave into drawpoints called entries. Air-cooled, V-8 diesel-powered, rubber-tired, load-haul dump (LHD) vehicles were used to haul the ore to the underground crusher and dump it into the ore crusher; it was transported by conveyor belt horizontally 825 meters, then lifted to the surface by a skip. The other types of haulage equipment used in this mine also were diesel powered and rubber tired. All haulageways were through reliable rock or were heavily reinforced with concrete and steel. The mine used a mixture of incandescent, mercury-arc, and fluorescent lighting.

The noise levels for mine 4 were made in a West Virginia mine where room-and-pillar mining techniques were used. The measurements were made primarily in a section where overburden was approximately 600 to 900 feet. Mining was accomplished using a continuous miner, head-loader, shuttle cars (buggies), conveyor belt, and electric trolley haulage. The electric trolley and the shuttle cars were powered by 300 volts dc. All other equipment, including fans and rock dusting machines, was ac powered.

The noise measurements taken in haulageways of these mines tended to show magnetic field strengths typically 60 to 70 dB μA/m up to a few kilohertz, which then decreases sharply above 8 to 12 kHz.

As seen in figure 3-32, the EM noise amplitude decreases with increasing frequency; however, three propagation mechanisms must be considered: (1) Through the earth, (2) through the entries supported by metallic structures and conductors, and (3) through the entries where they serve as a "waveguide." For propagation through the entries, it would appear, from the data presented, that selection of frequencies much greater than 100 kHz would be desirable.

For situations in which the propagation is directly through the earth, attenuation (signal loss) increases as frequency is increased. Because of lower attenuation at lower frequencies, better signal-to-noise ratios exist at low frequency despite the higher noise levels.

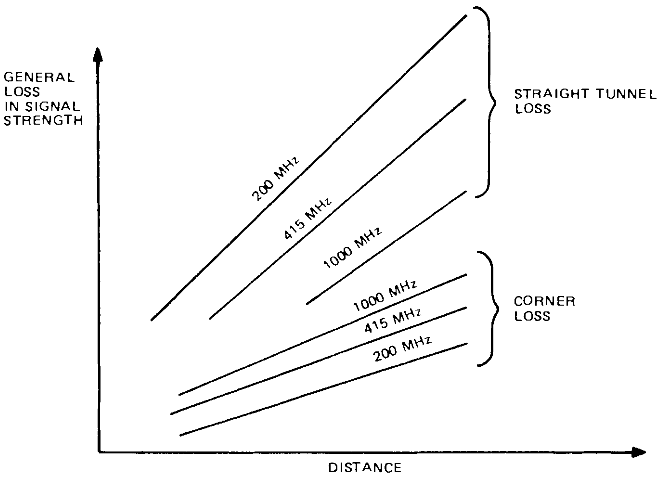

FIGURE 3-32. - EM noise amplitude decrease with increasing frequency.

3.5.2d.ii Signal Attenuation in the Haulageway

As a radio signal travels down a haulageway or tunnel, its strength decreases. Typical signal attenuation along a straight tunnel, for three different radio frequencies, is shown in figure 3-32. Transmission loss may be combined directly with transmitter power and antenna gains to determine the received signal for any candidate UHF system. In terms of transmission loss, a pair of 1-watt UHF walkie-talkies has a range of 143 to 146 dB.

Significant propagation characteristics apparent from figure 3-32 are--

Attenuation (in decibels) increases nearly linearly with increasing distance.

Transmission loss decreases significantly at a given distance as the frequency is increased.

3.5.2d.iii Signal Attenuation Around Corners

Observed signal attenuation around a corner is also shown in figure 3-32. Corner attenuation is plotted in decibels relative to the signal level observed in the center of the main tunnel. Figure 3-32 shows that signal attenuation around a corner is considerable. Because of the high attenuation of a single corner, propagation around multiple corners is even more severely attenuated.

Although it is an advantage to operate at a higher frequency in a straight tunnel, the higher frequencies suffer the greatest loss in turning a corner. Therefore, the choice of frequency is often dictated by the type of coverage desired.

Based on the interference and signal attenuation rates observed, the effective communication range for UHF radios can be predicted. Figure 3-33 shows the predicted range for a 1,000-MHz, 1-watt portable transceiver.

The presence of stoppings for direction of airflow, passages blocked by machinery, or blockage caused by a roof fall seriously limits the communication range of a UHF system. Obstructions highly attenuate all UHF signal transfer, thus making the same systems impractical for some mine applications.

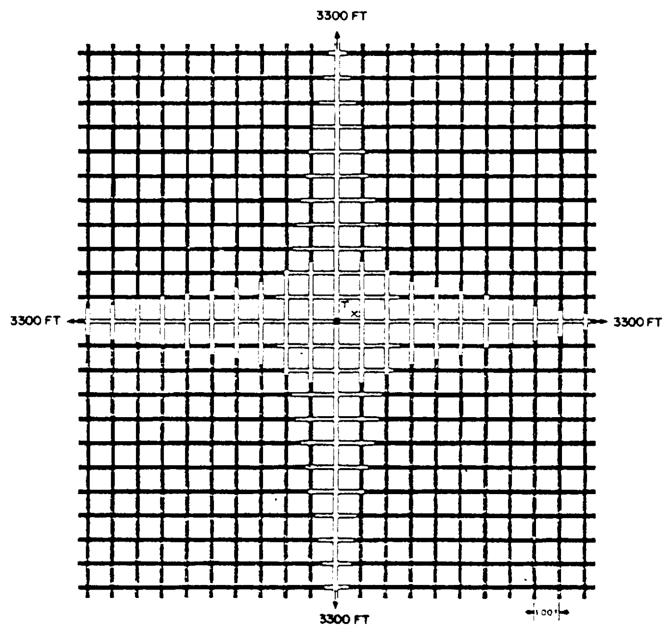

FIGURE 3-33. - Predicted range for 1,000-MHz, 1-watt portable transceiver.

3.5.3 Belt Haulage

Mines using conveyor belts to move coal or ore underground usually have a secondary transportation system for the movement of men and materials. When the man-material transportation system is tracked-trolley, the obvious solution to haulageway communication requirements is the trolley phone system described in section 3.5.1. If the man-material transportation system is nontrolley, then some form of radio, leaky feeder, or wired phone system is required.

A common practice in mines using belt haulage is to locate telephones at the intersections of all mains and submains, and at the head and tail of all working conveyor belts. (Belt fires most often occur at these points.) In the absence of trolley phones, belt haulage mines also usually locate phones approximately every 600 feet along the belts. These phones are installed for the life of the mine and are seldom moved.

Although a fully developed submain might have butt entry ports every 600 feet along its length, telephones are required only at the active or working butt entry ports. This usually limits the maximum number of phones per submain to six, owing to the capacity of most haulage systems. These phones are moved about every year or so until all panels in the submain have been developed. If a feeder belt is used in the submain, additional phones are recommended at the head and tail of these belts.

Phones permanently installed at the head and tail, and at other strategic locations along the belt, usually meet the communication requirements during normal day-to-day operations. The drawback to any wired phone system is that a miner must be at a phone to make or receive a call. Communication with belt maintenance or inspection personnel moving along the haulageway can only be accomplished by some form of radio link. The same systems described in section 3.5.2 (nontrolley haulage) can be utilized to meet the communication requirements in belt haulageways.

3.6 Special Requirements

This section describes ways of meeting those special communication requirements not directly related to the mine entrance (section 3.2), permanent and semipermanent locations (section 3.3), mining areas (section 3.4), and haulageways (section 3.5). Major topics included in this area of special requirements include communications with roving or isolated personnel and motorman-to-snapper communications.

3.6.1 The Roving or Isolated Miner

A modern mine is a vast underground complex of working sections, haulageways, and repair shops, which extends for several square miles underground. Key personnel may not work in fixed locations; for instance, a section foreman may be assigned to a single section, but that section could embrace a vast area, or maintenance personnel or electricians could be anywhere in the mine at any time. Because such personnel are important to the smooth operation and high productivity of a mine, considerable production losses can occur if they cannot be located when they are needed.

Inspectors and other management personnel may also be anywhere in the underground complex. These people need to stay in continuous contact with the communication center so that they can be informed of any emergencies that might arise and/or make management decisions.

The maintenance crew is also spread throughout the mine. To receive repair requests and dispatch his crews for emergency or nonscheduled repair work, a maintenance foreman must be able to contact individual crew members dispersed throughout the mine.

Communication requirements to and from these key individuals can only be completely satisfied by a wireless (radio) paging or walkie-talkie system. Several paging systems are presently available to meet these requirements. The small lightweight pagers that can be carried by roving personnel are classified as one of three types:

Beepers (call alert).

One-way-voice (pocket pagers).

Two-way-voice (walkie-talkies).

One shortcoming of the first two types of systems (beepers and pocket pagers) is that the person initiating the page has no way of knowing if the page has been received. This can be especially critical in the case of the pocket pager systems where voice messages can be transmitted to the person being paged. Because the pocket pager is a receive-only device, the person being paged cannot directly notify the dispatcher or person making the page that he has received the message. Therefore, one-way-voice (pocket) pagers should only be used for paging messages ("call the dispatcher," "report to the maintenance area," etc.). Instructions such as "shut off the number 2 pump" should not be given using one-way communication devices unless it can be verified that the message was received and acted upon. The advantages gained by any of the three types of paging systems are directly related to the reduced time required to contact key individuals when their location underground is unknown. Even with the simplest beeper systems, the person being paged can, within a few seconds, be headed for a section phone to take a message.

3.6.1a One-Way-Voice (Pocket) Pagers

In a mine that uses rail haulage vehicles powered from an overhead trolley wire locomotive or jeep, carrier phones allow the vehicle operators to communicate with each other and with a dispatcher who controls the flow of traffic. As explained in section 2.4, the trolley line itself is the communication link between all the vehicles and the dispatcher.

However, communication need not be limited to phones connected to the trolley line. A special carrier-current tone signal can also be impressed on the trolley line, which will function as a long-line antenna, broadcasting the tone signal into the mine where it can be received by special pocket radio pagers (fig. 3-34). Hardware is now commercially available that allows a dispatcher to voice-page selected individuals, deliver short messages, or inform them where to go to receive detailed instructions. Figure 3-35 is a block diagram of a general radio paging system based on carrier-current techniques. A carrier phone, located at some central loction such as a dispatcher's room, is equipped with a small pushbutton-encoder unit. This unit causes the carrier phone to transmit short tone bursts whose frequency depends on which pushbutton was pushed. These tone bursts are transmitted from the carrier phone in exactly the same way that a voice signal would be sent out.

FIGURE 3-34. - Miner equipped with pocket radiopager.

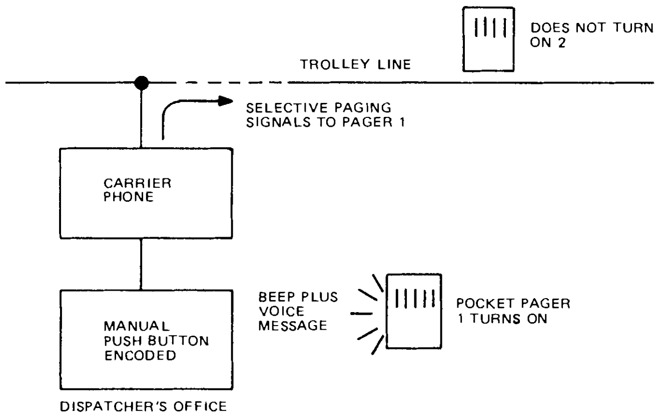

FIGURE 3-35. - Block diagram of general radio-paging system.

The pocket receivers that have been developed to respond to these tones are really small FM radio receivers that are activated by the tones and remain on for about 15 seconds. Once the tones have been sent, the dispatcher then talks into his carrier phone in the usual manner. Only the pocket pager activated by the tones will receive the message, so that the dispatcher can selectively radio-page any individual. In an emergency, a special tone can activate all pagers at once. The pocket pager is a receiver only and cannot be used to talk back to the dispatcher. Therefore, the system should be used only for paging, not for giving instructions.

The system shown in figure 3-35 is designed so that only the dispatcher can initiate a page, because he is the only one who has a carrier phone equipped with an encoder. However, other encoders could be used with other carrier phones, if necessary. Figure 3-36 shows a system in which the encoder is remotely accessed by a dial telephone line. Thus, any dial telephone associated with the mine switchboard (PBX) could be used to initiate a page without ever being near the encoder. Such a system offers an advantage should many people have to page into the mine from several surface locations. To operate the system, a user goes to a telephone and dials the number assigned to the pager he or she wishes to call. The encoder converts the telephone dial pulses into tones and transmits them via the carrier phone. The tones turn on the

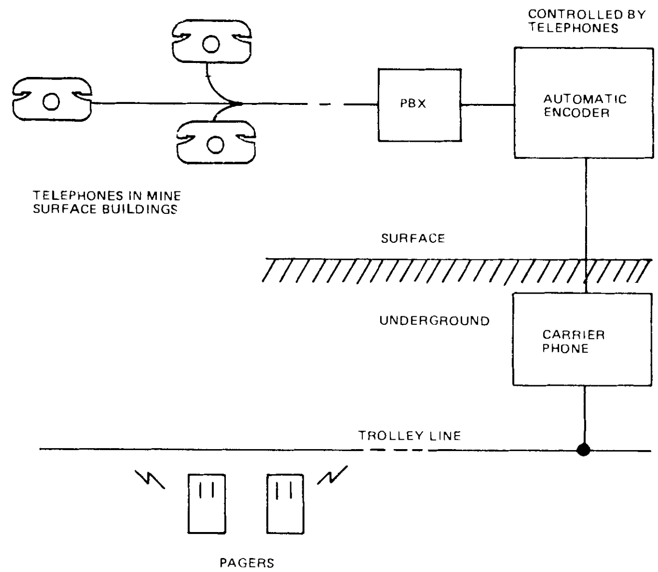

FIGURE 3-36. - Block diagram of system with remotely accessed encoder.

desired pager, at which time the user can speak into the mouthpiece to deliver the voice message.

Existing pager receivers are equipped with a small internal timer that automatically turns the device off after a preselected time, usually 15 seconds. A continuous "On" mode is usually not desirable because it wastes battery power. With the automatic time-out feature, batteries last for months. However, there are times when the continuous monitoring of the radio paging system is important to certain maintenance personnel.

A radio paging system can be operated on a special channel (frequency), or on the regular channel used by the locomotives. The only difference is that if both are included on the same regular channel, all the carrier phones will hear the paging traffic, but the pagers will hear only what is sent to them directly.

A radio paging system can incorporate both the automatic encoded system (fig. 3-36) and a roof-bolt antenna system (fig. 3-37). The automatic encoder and carrier phone can be located on the surface; all else is underground. The in-mine roof bolts are separated by about 300 feet and connected to the carrier

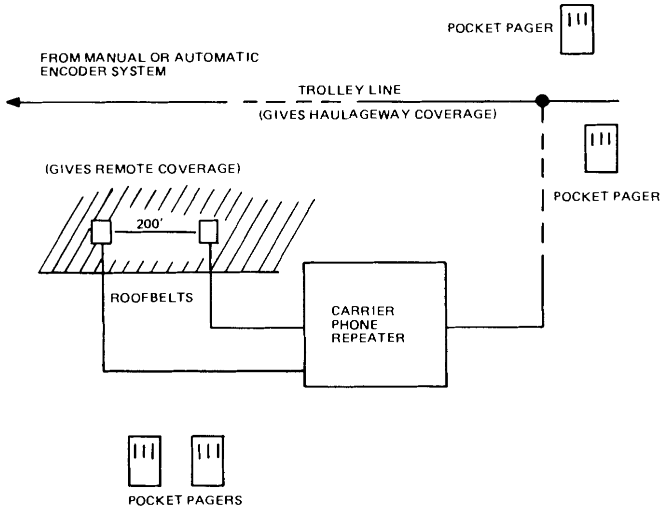

FIGURE 3-37. - Block diagram of system using roof-bolt-type antenna.

phone by No. 12 wire. With this system, paging can be accomplished from as far as 500 feet from a roof bolt antenna.

3.6.2 Motorman-to-Snapper

Many mines use loading track loops for loading mined coal or ore at the sections before transporting it to the surface. This type of operation involves the coordinated activities of two individuals: a "snapper" or "swamper" who couples and uncouples the cars; and a locomotive operator, or motorman, who moves the train backward and forward at prescribed times. If the snapper is not in the clear when the train is moved, its sudden motion can injure or kill him. Thus, effective communication between the motorman and snapper is vital.

Because of the curvature of the loop track (fig. 3-38) and the location of the locomotive on the main haulage track, the two individuals are not usually within sight or hearing of each other. Without communication or at least some system of signaling, coordination is difficult unless other workers are stationed alongside the track to relay information. However, this wastes time and manpower. It is clear that the safety and efficiency of the loading operation would be vastly improved if there were a reliable communication link between the motorman and snapper.

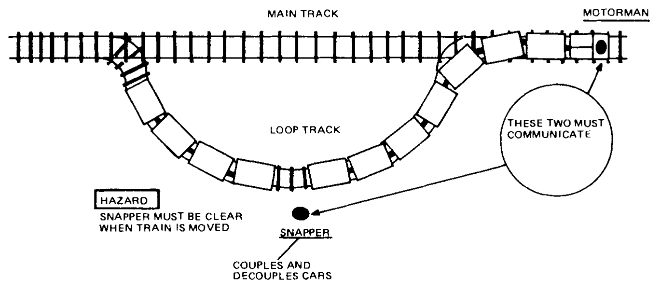

FIGURE 3-38. - Diagram showing need for communication in haulage loop-around.

The design of any practical system to meet the communication needs between motorman and snapper requires that it does not interfere with other communications, is convenient, has a restricted range so that similar systems can be used elsewhere in the mine, and can be built with commercially available hardware. Typically, a range of 1,500 feet or less is all that is necessary to assure adequate coverage for the maximum separation between the snapper and motorman. Two systems that can presently be implemented using commmercially available hardware are the telephone and trolley-carrier phone system and the walkie-talkie radio system.

3.6.2a Telephone and Trolley-Carrier Phone System

In the telephone and trolley-carrier phone system (fig. 3-39), the snapper communicates by means of a belt-carried,

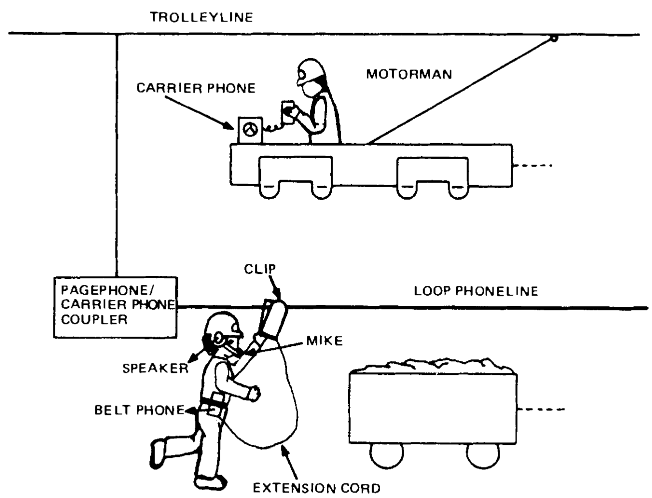

FIGURE 3-39. - Telephone and trolley-carrier phone system.

miniature mine telephone known as a belt phone. A phone line is installed on the rib or roof of the mine along one side of the loading track. The belt phone can be connected to this line by an extension cord that has insulation-piercing clips at one end. Alternatively, receptacles that allow the belt phone to be plugged in at convenient points can be provided on the line.

A pager-phone-to-carrier-phone coupler connects the phone line and the trolley line. Phone line signals are converted to trolley line signals and vice versa by this coupler. The motorman communicates by a trolley phone, which operates on a frequency different from that of the haulage communications.

CAUTION.--Indiscriminate use of this procedure is not recommended. MSHA inspectors should be consulted before any carrier-phone-to-pager-phone coupling is installed.

If duplicate systems are used in a mine, the range of the trolley line signals has to be restricted by appropriately attenuating the transmitter output. This system can be implemented using standard trolley phones and phone-line-to-trolley-line couplers. In addition, a belt phone (fig. 3-40) is now commercially available. Equipped with a hardhat-mounted speaker and an adjustable-boom-type microphone, it has outgoing paging capability and will operate compatibly with available phone-line-to-trolley-line couplers.

At least one mine has successfully used an interface system between the phone and trolley lines to provide motorman-snapper communication. The system is diagrammed in figure 3-41. A remote interface, fabricated by technicians at the mine, acts as a coupler between the trolley line and a dedicated phone line. The motorman can communicate via the existing carrier phone system, whereas the snapper must communicate via the phone line using a modified telephone handset. A twisted-pair phone line, with jackboxes connected at 50-foot intervals, is strung up in the loop-track area and connects to the dedicated phone line. The snapper plugs his handset into a nearby jackbox to establish communication to the motorman.

FIGURE 3-40. - Miner wearing belt phone.

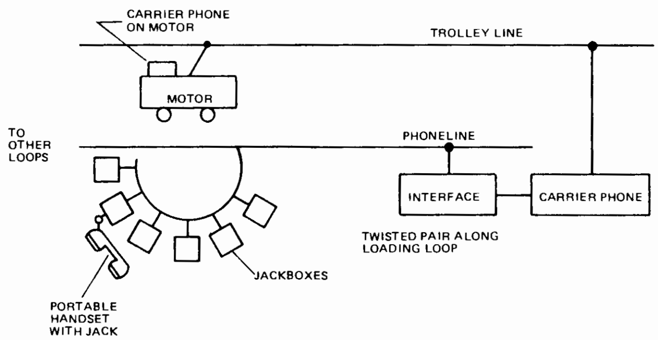

FIGURE 3-41. - Diagram of interface system between phone and trolley lines.

3.6.2b Walkie-Talkie System

The walkie-talkie radio system uses UHF portable radio equipment. Both the motorman and snapper are equipped with walkie-talkies (fig. 3-42).

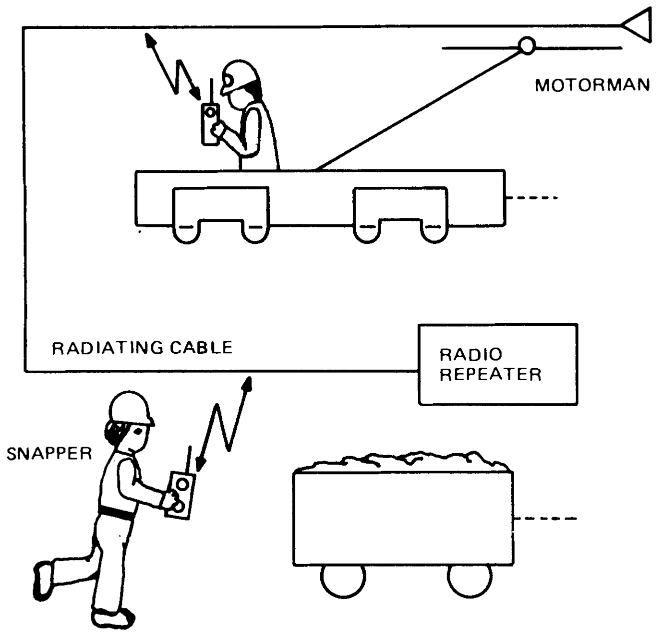

FIGURE 3-42. - Motorman and snapper walkie-talkie system.

Because of the curvature of the loop tunnel, propagation of radio waves at UHF is severely restricted. In fact, direct radio communication between the two individuals may not be possible in some cases. However, this deficiency can be overcome with a dual-frequency radio repeater connected to a radiating cable. The cable carries the radio signals, and the repeater effectively boosts them to a higher power level. The coaxial cable extends along the loading track and down the main haulageway far enough to assure communication coverage to the motorman. Cables several hundred feet shorter can be used if an approprate antenna is connected at the end. Commercially available portable radio transceivers and repeaters can be used to implement this system.

A medium-frequency radio transceiver (520 kHz) with sufficient range has been developed that makes snapper-motorman communications possible without installing additional cables. Transmission is aided by the conductors normally present in the loop-around.

Effective communication between the snapper and motorman can provide the coordination needed to eliminate uncertainties regarding train movement in the mine. This results in improved efficiency and a reduction in the num-ber of accidents related to the loading operation. Systems can be custom made from available telephone and carrier phone equipment. Leaky-feeder UHF equipment is similarly available for custom systems.

3.7 Emergency Communications

There are two conditions under which a communication system should operate. These are normal operations (regular day-to-day operation) and emergency conditions. The need for reliable underground communications following a disaster is obvious. Two major requirements for any emergency communication system follow:

1. The system must work following the disaster. (This implies that the system worked before the disaster and that the system is protected from, or immune to, fire, explosion, roof fall, etc.)

2. Miners must be familiar with operation of the system. (Mistakes are easy to make during periods of high emotional stress.)

It should be recognized that there are advantages in combining any emergency communication system into the system used for normal day-to-day operations. In this way, miners can become familiar enough with the system to operate it during disaster conditions. Daily use of the system also provides a mechanism of regular testing, thus insuring that the system will be operational.

3.7.1 Detecting and Locating the Trapped Miner

The history of coal mine disasters has established a need for a simple, reliable system for locating and communicating with miners trapped underground. Such a system will not only increase the chances of a successful rescue, but will also reduce the risks to the rescue team by keeping them from searching the wrong locations.

The problems of finding miners trapped underground can be illustrated by a disaster that occurred in 1945, in which 24 men were killed by an explosion. Figure 3-43 shows the location where nine men barricaded themselves for 53 hours in that particular incident. Rescue crews tried for 2 days to reach the active area of the mine in 5 and 6 Lefts while being hampered by caved workings, fires, smoke, gas, and loose roof. Three days later, while exploring 9 Right, they found footprints. After investigating, they found a chalk-marked board indicating that five men were in 4 Left entry. In 5 Left, another mark was found directing searchers to second Left off of 5 Left. Seven of the nine men survived the ordeal. All might have lived if their location had been known so they could have been reached sooner. The time required to rescue barricaded miners is critical. In the recorded cases of barricading, 75 percent of the survivors were rescued within 10 hours.

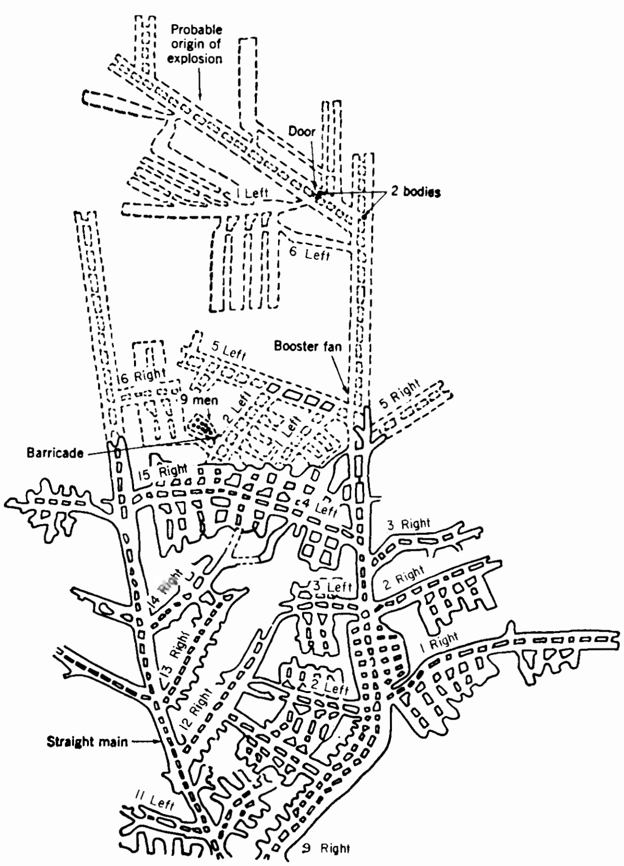

FIGURE 3-43. - Part of mine showing area to which miners retreated and erected imperfect barricade.

After a disaster, miners who manage to escape can direct rescue teams to those parts of the mine where others may remain trapped. The nature of the mine workings and the circumstances of the disaster can also be used in locating survivors, but all of these techniques are based on guesswork. Accurate knowledge of the location of trapped men is required to increase their chances for survival and to reduce the hazards to the rescue team that might otherwise conduct an unnecessary, futile search in dangerous, incorrect areas.

It is obvious that any information that could be exchanged between the trapped miners and the rescuers during a rescue effort would be advantageous. Information such as unusual conditions known to the miners trapped, or medical advice for them to follow until aid arrived, are two examples. In other words, a system that would provide the location of trapped miners and permit communication with them would increase the probability of their rescue and also reduce hazards to the rescue and recovery team. Two systems for locating and communicating with trapped miners have been developed: a seismic system and an electromagnetic system.

The seismic system relies on detection of small ground vibrations resulting from a miner(s) banging on the roof or ribs with some heavy object. This system is presently operational and is being improved continuously. In this system, the trapped miner signals on the mine floor or roof with any heavy object and seismic detectors (geophones) on the surface are used to detect these signals. Computation of the location of the trapped miner by using the difference in the arrival time of the signals at various geophone positions on the surface has been quite successful. A seismic location system has the advantage that the miners do not require any special equipment and need only to be trained in how and when to signal. The disadvantage is that discontinuities in the overburden can significantly affect rescue signal propagation relative to both detection and computation of location of the signal.

Additionally, in a rescue and recovery operation, the time required to deploy and relocate, if necessary, a massive geophone array may hamper the progress desired. However, the seismic system does provide the trapped miner with an additional degree of protection when no other method of communication can be established. The Mine Safety and Health Administration maintains a seismic rescue system as part of its Mine Emergency Operations group. All miners should obtain MSHA stickers for their hard hats (fig. 2-26) in case they should become entrapped.

The electromagnetic system relies on a small voice frequency (VF) transmitter that can be carried by the miner, and surface receivers that "listen" for the signals broadcast directly through the earth or through the mine workings by the miner's transmitter. Basic development of VF EM systems is completed, and prototype hardware is in the testing phase.

A typical trapped-miner transmitter (fig. 3-44) weighs one-half pound and can be worn on the belt. Cap lamp battery units also exist. In an emergency, and when it is decided that all routes of escape are closed, the antenna wire is uncoiled, laid out in as large a loop as possible, and connected to the transmitter. The transmitter and loop antenna produce a magnetic field, as shown in figure 3-45. The direction of these signal-field lines can be used to pinpoint the location of the underground loop antenna. By measurements taken on the surface, the location of the antenna can be determined within a few feet.

After detecting and locating a trapped miner, the surface search team can establish a voice down-link communications path to the men underground. This voice link is established by deploying a large loop antenna directly above the trapped miners and connected it to a very powerful amplifier and voice system (fig. 3-46). By speaking into the microphone associated with the system, strong electromagnetic signals are generated and transmitted by the loop antenna. These signals penetrate the earth, and the trapped miners can hear actual voice from the surface on their transceiver. The surface can then ask key questions to

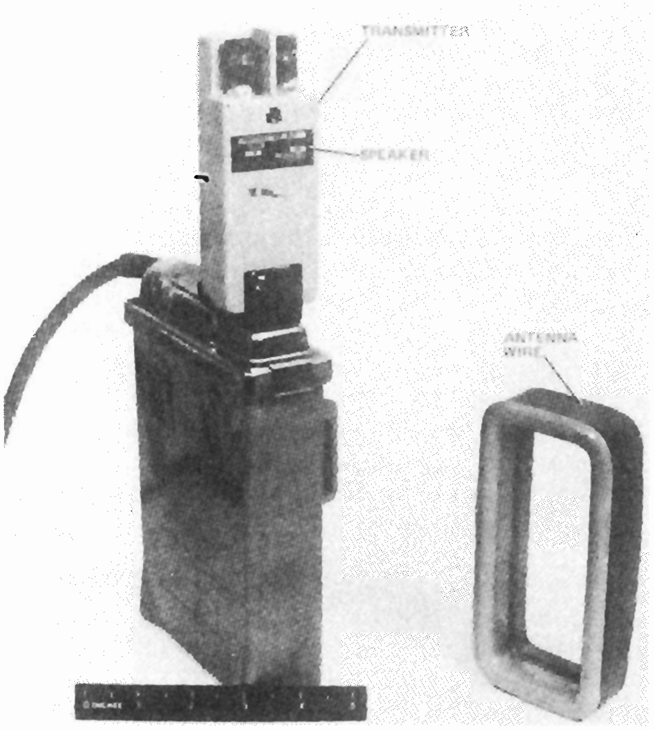

FIGURE 3-44. - Underground-miner-carried VF equipment for signaling surface rescue crew.

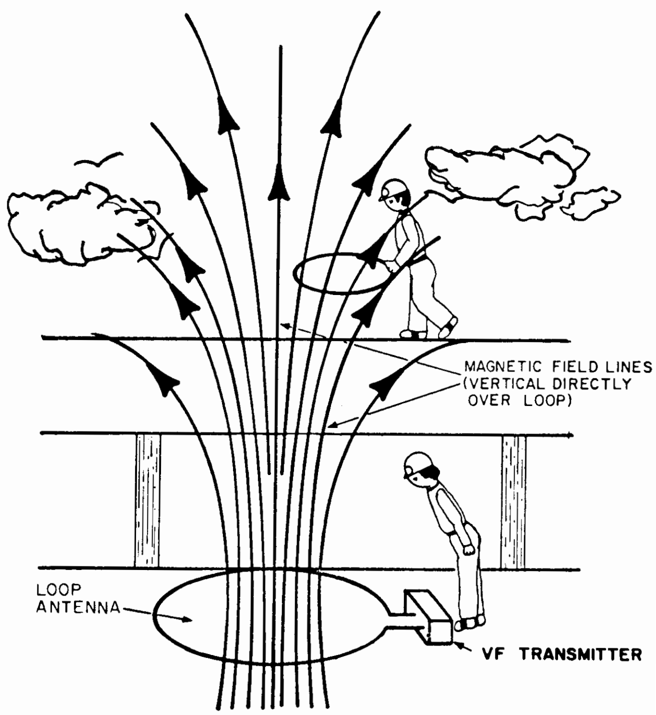

FIGURE 3-45. - Production of a magnetic field by transmitter and loop antenna.

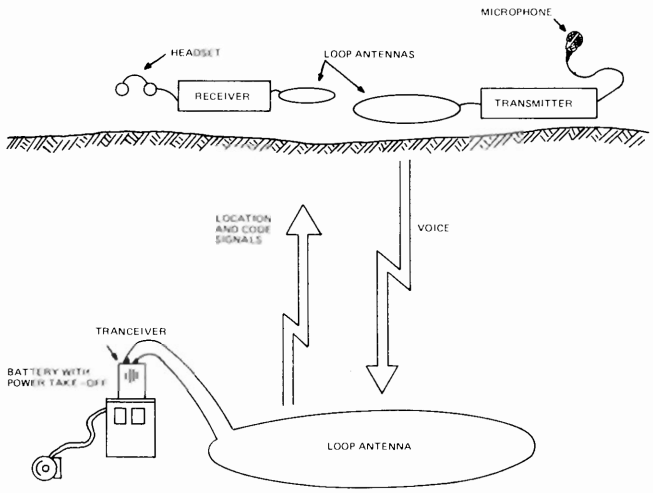

FIGURE 3-46. - Through-the-earth transmission system.

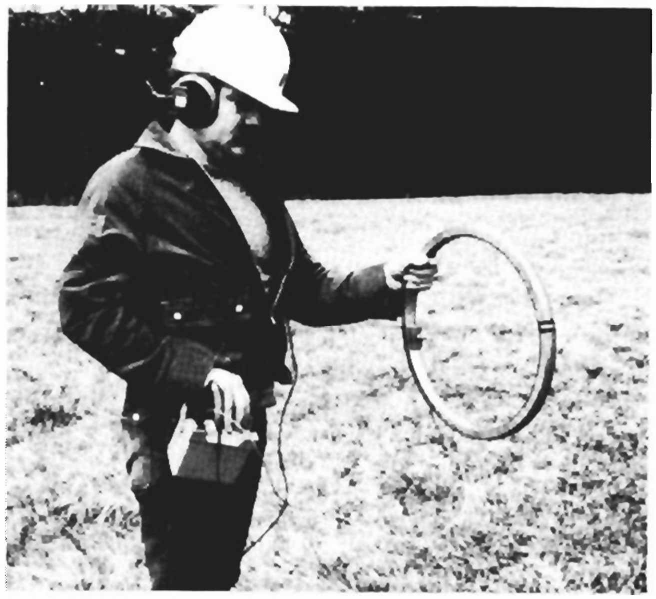

FIGURE 3-47. - Surface VF receiver and loop antenna in use at simulated mine disaster.

ascertain the conditions underground. As an example, they can ask the trapped miners to key three pulses of signal for a "yes" answer and two pulses for a "no" answer. This type of down-link voice and up-link code signaling system allows the surface team to learn anything they wish about the situation underground and also allows them to give instructions or information concerning escape routes and rescue attempts.

One advantage of an electromagnetic system over a seismic system is that the EM transmitter operates continuously once deployed and will function for many hours, or even days, from one cap lamp battery. Besides operating continuously, its electrical signal is a known rhythmic "beep," which is much easier to detect than the random thumps of a miner pounding on the ribs or roof. Another advantage is that the detection receiver can be readily carried by one miner (fig. 3-47) and can be used to cover a reasonably large area. It can also be used by underground rescue teams since it is permissible. A version of the surface receiver has been adapted for use in helicopters. With this unit, large areas can be scanned quickly. Once a signal is detected, portable surface-carried units can obtain an exact fix. The surface gear for a seismic system, on the other hand, is complex and stationary. Its deployment site must be carefully selected. If it is not within 2,000 feet of the signal source, it probably will not work. In a large mine, this limitation is a serious handicap. In mountainous terrain, setting up the seismic geophones can present especially difficult problems.

3.7.2 Refuge Shelter

When it appears to be impossible to escape, or imprudent to attempt escape, following a mine fire or explosion, miners are trained to isolate themselves from toxic gases and smoke by erecting barricades. Although many miners have been rescued from behind barricades, some have died behind inadequately constructed barricades. As a solution to this problem, sectional or central refuge chambers have been established by some companies. If a chamber is constructed, some form of communication to the surface should be included to inform rescue crews that the chamber is being used and of the condition of its occupants.

Communication to a refuge shelter could be provided by means of a borehole equipped with a telephone pair connecting to the surface, by existing wiring within the mine, or by some form of through-the-earth system. The in-mine telephone system would be the least reliable after an explosion unless the cable installation had been specifically hardened. Boreholes would be highly reliable but would require a new borehole for each refuge chamber or whenever a refuge chamber was moved.

3.7.3 Rescue Team Communications

Even though searching a mine after a fire or explosion is a slow and often dangerous job, the rescue team must reach any trapped or barricaded miners as soon as possible. Effective communication between the rescue team and the surface or base camp, as well as communication between individual members of the team, is an essential element in any successful rescue attempt.

One method that has proven effective in maintaining communication to and from the rescue team is illustrated in figure 3-48. In this relatively simple system the rescue team splices into a good phone line and then unrolls line from a spool as they advance into the mine. During a recent rescue, this type of system provided good communication even after the rescue team had traveled approximately a mile along a haulageway and then descended another 1,200 feet down a shaft from an underground headframe.

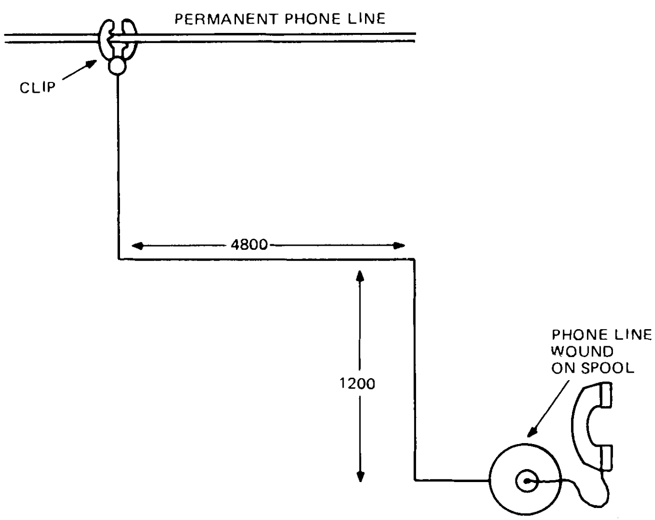

FIGURE 3-48. - Effective method for maintaining communication to and from rescue team.

The primary advantage of this type of system is that it is simple and yet usually provides good-quality voice communication. Also the phone wire trailed behind the rescue team provides a physical link back out of the search area. This link can become an important factor if the team must retreat under conditions of poor visibility, or if a second rescue team wishes to "follow" the first team. The disadvantages of this type of system are (1) the wire spool, which may be heavy, must be transported by the rescue team, and (2) the wire strung behind the rescue team is susceptible to damage from secondary explosions or roof falls.

3.7.4 Medium-Frequency Rescue Systems

Considerable research has been conducted within the last 8 years in the area of underground MF transmissions. This research showed that MF signals could propagate for great distances in most geologies and offered the hope of a whole-mine radio system. The Bureau of Mines and the South African Chamber of Mines (SACM) pursued research independently.

Around 1974, SACM introduced a new single-sideband system and followed up later with another designed especially for rescue team use. Performance in South Africa was reported to be good. The evaluation of these units in U.S. mines showed them to be inadequate. The type of modulation used [single sideband (SSB)] made them sensitive to electromagnetic interference (EMI). In addition, power level was far too low and inefficiencies in both circuit and antenna designs produced short-range performance.

The Bureau's approach to the problem was more fundamental. A program was designed and executed to study in-mine MF propagation and learn how it interacted with the complex environment. This environment consists of various geological factors such as stratified layers of different electrical parameters, entry size, local conductors, EMI, etc.

Figure 3-49 is a simplified geometry of an in-mine site that illustrates one of the most important findings of the measurement program--the "coal seam mode." For this mode to exist, the coal seam conductivity (σ_c) must be several orders of magnitude less than that of the rock (σ_r). A loop antenna that is at least partially vertically oriented, produces a vertical electric field (E_Z) and horizontal magnetic field ($H\phi$). In the rock, the fields diminish exponentially in the Z-direction. In the coal seam, the fields diminish exponentially at a rate determined by the attenuation constant (α) which in turn depends upon the electrical properties of the coal. An inverse square-foot factor also exists because of spreading. The effect is that the wave, to a large degree, is trapped between the highly conducting rock layers and propagates long distances within the lower conducting coal seam. The fact that the coal may have entries and crosscuts is of minor consequence.

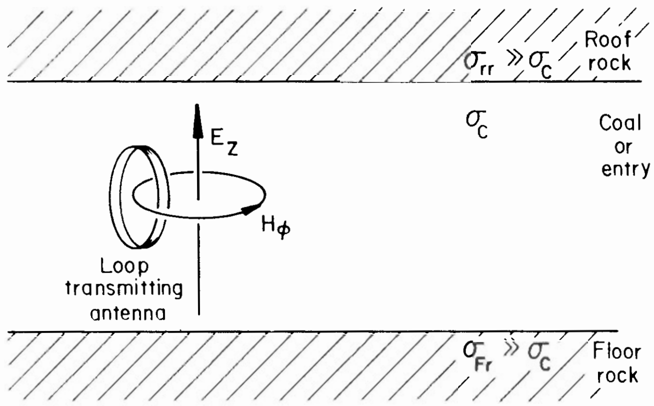

FIGURE 3-49. - Coal seam mode.

In the presence of conductors, the picture changes considerably. In this case, the effects of these conductors can totally dominate over the effects of the geology. In general, the presence of conductors (rails, trolley lines, phone lines) is advantageous.

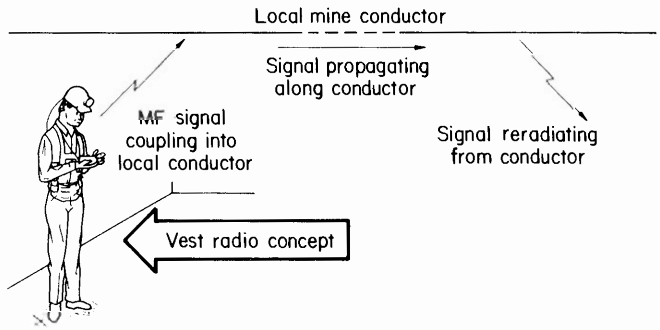

FIGURE 3-50. - MF parasitic coupling and reradiation.

MF signals can couple into, and reradiate from, continuous conductors in such a way that these conductors become not only the transmission medium but also the antenna system for the signals. Figure 3-50 illustrates this concept. The most favorable frequency depends to some extent on the relationship between the geology and existing conductors. The frequency effects are quite broad. Anything from 400 to 800 kHz is usually adequate.

3.7.4a Specific Application of MF Communications to Rescue Teams

The low attenuation of MF signals in many stratified geologies, such as coal mines, can be of great benefit to rescue teams. If existing mine wiring (like powerlines or belt lines) are present, the range is even greater. This permits a rescue team member to stay in communication with other members, the fresh air base, and outside disaster control centers.

To date, MF technology has not been specifically applied to rescue team communications. Such application is the second step in the Bureau's overall MF communications program. However, there is no basic difference between operational MF systems and postdisaster MF systems. By October 1982, the Bureau's operational MF systems was in place in several cooperating underground mines. By October 1983, performance evaluation of the systems will be completed. As the performance proceeds, emphasis will be directed to specific postdisaster-rescue applications.

3.7.4b System Concepts

The main advantage of MF communication is simplicity. Figure 3-51 shows a rescue team member equipped with a prototype MF vest radio. This vest radio permits rescue team members to maintain local communications (fig. 3-52).

In most cases, rescue teams will utilize a lifeline for rapid retreat in case of smoke when visibility is limited. The lifeline offers interesting possibilities for MF radio communications. Some rescue teams actually use the line already to carry communications via sound-powered telephones. Such a scheme is both archaic and often ineffective.

Since this line is a continuous conductor back to the fresh air base, it provides a convenient parasitic path for MF communication as shown in figure 3-53. To assure even more reliable communications, physical audio links could be made with the lifeline as shown in figure 3-54. Such an approach provides redundancy via simultaneous audio and radio links.

Figure 3-55 illustrates a total MF base station for rescue team use. At the fresh air base, the briefing officer (as the individual is sometimes called) is equipped with a standard intrinsically safe base station or repeater; the officer could also be equipped with a vest. With such an arrangement, communications are possible not only between rescue team members, but also with the surface and with other distant rescue teams. In addition, it also provides a possible link to the trapped miners.

Since existing mine wiring is extensive and minewide, it is easily seen that it provides yet another redundant link for the rescue team members. Since other rescue teams are also in the vicinity of mine wiring, interteam communications are possible if desired. This concept of interteam communications is a radical departure from existing procedures. It will permit one rescue team, in one part of the mine, to modify the ventilation in such a manner that it does not degrade

FIGURE 3-51. - Rescue team member with MF vest radio.

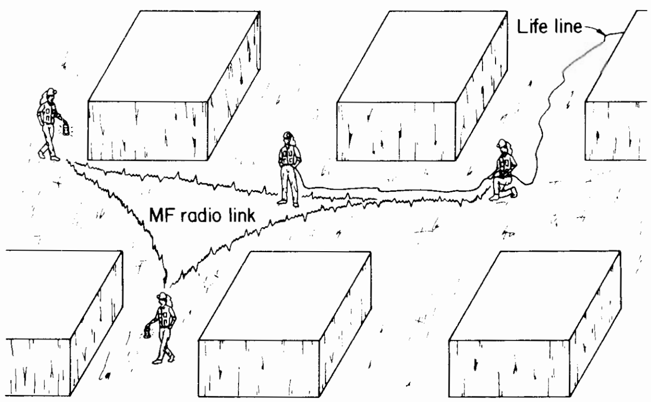

FIGURE 3-52. - Basic MF communications among rescue team members.

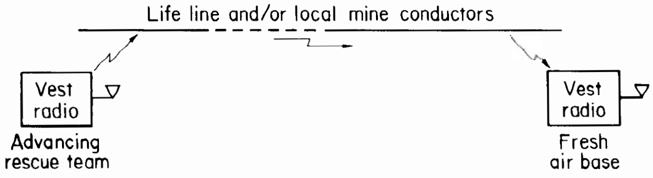

FIGURE 3-53. - Lifeline as a parasitic MF path.

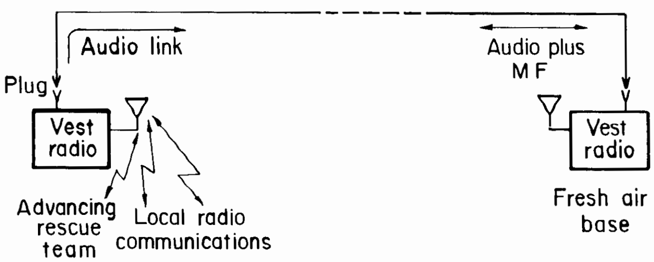

FIGURE 3-54. - Lifeline as a redundant communications line for MF and audio communication.

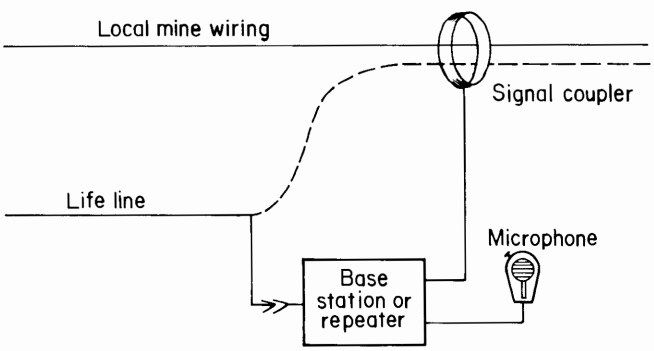

FIGURE 3-55. - Total MF base station for rescue teams.

the ventilation in the vicinity of another rescue team. Equally important is the fact that trapped miners are also probably in the vicinity of existing mine wiring.

3.7.4c Location and Communications Systems for the Rescue of Trapped Miners

So far this section has primarily addressed the application of MF communication to rescue teams. However, the ultimate objective of the rescue operation is to reach trapped miners in a timely manner before they succumb to the effects of injury, exposure, or toxic atmospheres. To this end, rescue team communications is but a part. The key to successful rescue lies in the rapid location of the trapped miners. Without this, valuable time can be wasted in diverting rescue efforts to the wrong area, often with tragic results.

Bureau research in the area of location has been addressed by through-the-earth seismic and EM systems. In the seismic system, trapped miners pound on the roof or ribs of the mine to generate seismic vibrations. These vibrations travel through the overburden to the surface where they can be detected by sensitive transducers called geophones. Computer analysis of the arrival times of the seismic signals at the various geophones permits the source to be accurately located. This system is operational and is kept in readiness by MSHA Mine Emergency Operations. Present Bureau research in EM means to locate and communicate with trapped miners is shown in figure 3-56. The system consists of two parts, a transceiver that is normally carried on the miner's belt and a surface system for detection and communications.

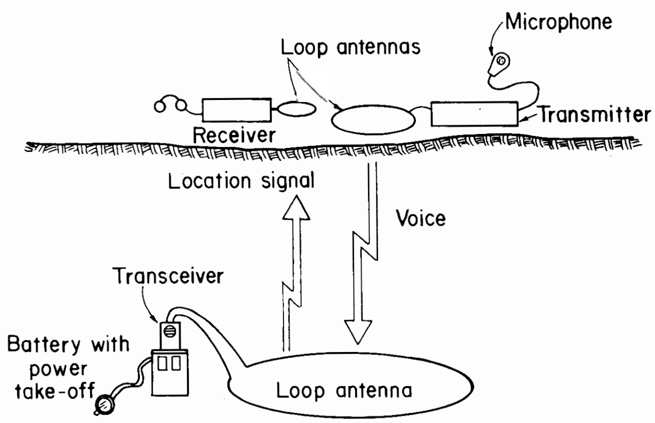

FIGURE 3-56. - Voice frequency electromagnetic system for location and communication with trapped miners.

In operation, the trapped miner removes the transceiver from the belt, deploys a self-contained loop antenna, and attaches the transceiver to a special cap lamp battery. This antenna consists of 300 feet of No. 18 wire that must be deployed in the largest area possible to be effective. A location signal is transmitted directly through the earth.

On the surface, sensitive receivers detect the signal and locate the source. Once detection and location are made, a large surface transmitter is deployed above the trapped miner. This transmitter is powerful enough to send voice messages by radio, directly down through the earth.

The trapped miner's transceiver receives this voice. The surface personnel then ask the miner "yes-no" questions concerning his or her condition and that of the mine. The miner responds by simple on-off keying of the transceiver. In this manner a two-way communications link is established, entirely through the earth, and rescue operations can start in the most efficient manner.

Details of this EM system can be found in numerous reports. This is known as a voice frequency (VF) system because all communications take place in the VF band of 300 to 3,000 Hz.

The seismic system is very effective in mines up to 2,200 feet deep, and does not require the miner to be equipped with any special devices. However, it does require the miner to be able to pound. Injury or lack of a sufficiently heavy object with which to pound may render the system ineffective. The most serious drawback is that of time. The surface receiver station (geophones, field truck with computer, etc.) may take too long to set up. Bad weather and terrain can further delay the surface station deployment.

The EM-VF receiver system is less affected by adverse conditions on the surface because it is lighter and more easily transportable. However, it has its own disadvantages. The trapped miner must be equipped with a special transceiver, and must be able to deploy the antenna in a sufficiently large area. Injury or confined quarters may prevent deployment. In addition, under the best of conditions, the system has a range limit of about 1,000 feet. Although a new system is under development that will increase the range to 3,000 feet, this improvement comes about only with complex, slowly deployed surface equipment. Therefore, it will be subject to the same delays as the seismic system.

MF communication offers advantages over through-the-earth approaches by permitting in-mine communications to the trapped miners. This could be in addition to, or in place of, through-the-earth schemes that may fail because of excessive overburden or the inability of the trapped miner to deploy his or her end of the system successfully. Figure 3-57 illustrates this concept.

In this illustration, the trapped miner is equipped with a small MF transceiver built into the top of the cap lamp battery or worn on the belt. Note that this is exactly the same packaging concept used for the VF through-the-earth system shown in figure 3-56. The intent, however, is not to send a signal through the earth, but rather to induce a signal onto local mine wiring. If this is accomplished, the in-mine rescue team also

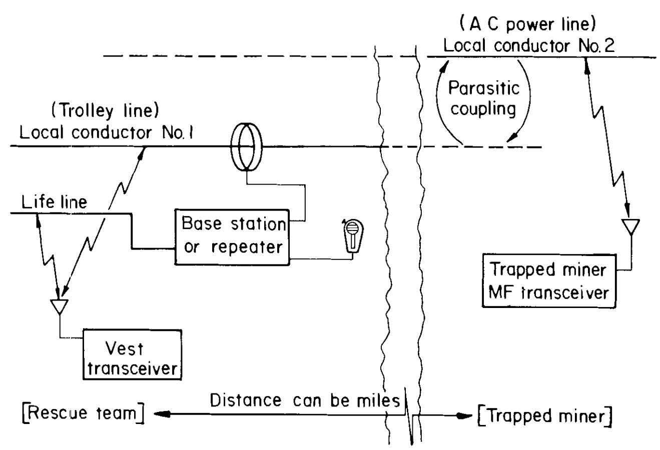

FIGURE 3-57. - MF in-mine location and communication system.

is likely to be in the vicinity of mine wiring and can receive the signal. It must be pointed out very clearly that mine wiring does *not* mean that one continuous assembly of wiring is involved. If the trapped miner is near a power cable and not near a trolley line, and the rescue team is near a trolley line and not near a power cable, this does not mean that a communications link between the two cannot exist. An induced MF signal on one type of conductor will parasitically couple to all others, even if there is no physical connection. This is the uniqueness of MF communication.

In operation, the trapped miner would deploy an MF loop antenna or coupler, preferably onto available local wiring. The coupler could be a small device of small volume similar to a current transformer. The loop could be a coupler that was unwound. In either case, the antenna is small. If nearby wiring does not exist, the loop could be deployed in hope of coupling to distant wiring. When so deployed, the transmitter sends out MF signals of narrow bandwidth that parasitically couple onto mine wiring, and are widely distributed. This can be received by the in-mine rescue team. If this occurs, they will use their more powerful MF equipment (vests or base stations) to establish a voice link to the trapped miner. By asking the trapped miner yes or no questions, his or her location can be learned. However, direct location via MF communication is impossible. The parasitic coupling characteristics of MF signals do not permit the through-the-earth VF type of location; the signal could be on many conductors.

Obviously VF and MF systems could be combined such that the benefits of both VF (fig. 3-56) and MF (fig. 3-57) could be obtained. Equally important is the fact that the MF trapped miner device could be used in nonemergency situations as a page receiver and thereby be a cost effective addition to a general mine communication system. Table 3-3 lists MF communication system specifications.

TABLE 3-3. - MF communication system specifications

Emissions, narrowband FM:	
Occupied bandwidth......................kHz..	10
Rf frequency............................kHz..	60-1,000
Peak deviation..........................kHz..	±2.5
Modulated frequency......................Hz..	200-2,500
Receiver, superheterodyne:	
Sensitivity.................................	1.0 µV (12-db sinad)
Selectivity.................................	8-pole crystal filter
IF 3-dB bandwidth (minimum)...........kHz..	12
IF 70-dB bandwidth (maximum)..........kHz..	22
RF bandwidth............................kHz..	60-1,000
Squelch.....................................	Noise operated and tone
Transmitter, push-pull, class B:	
Output power, W:	
Vest......................................	4.0
Vehicular.................................	20.0
Antenna magnetic moment (ATm^2):	
Vest..	2.1
Vehicular...................................	6.3
RF line coupler, transfer impedance (Z_T):	
1-in coupler, ohms:	
350 kHz...................................	10.0
520 kHz...................................	11.2
820 kHz...................................	17.8
4-in coupler, ohms:	
520 kHz...................................	10.6

3.7.4d Performance Data

In order to evaluate the potential of MF signals as a means to locate and communicate with trapped miners, and to provide communications for the actual rescue team operation, a test was conducted at the York Canyon Mine near Raton, N. Mex., in June 1982. This mine is a coal mine located in the York seam of the Raton Basin. The terrain is hilly such that the mine overburden varies from about 200 to 800 feet.

The mine has four main drift entries that are about 7,000 feet long. Off these entries, submains were driven and longwall mining occurs. A borehole is located at about the 7,000-foot mark. This borehole contains a twisted pair cable that is associated with the fire monitoring system on the longwall panels.

This is an ac mine that transports the coal by belt. Rubber-tired vehicles provide transportation for personnel and supplies. The distance from the portal, down the main entries to the longwall faces, can be nearly 15,000 feet).

At the mine portal, a MF signal coupler was attached to the mine telephone lines. This coupler was controlled by a standard MF base station. A second coupler and base station were placed at the top of the borehole. The coupler was clamped around the cable that went down the borehole.

Two personnel entered the mine and, by vehicle, traveled down the main entries to the vicinity of the borehole (7,000 feet). These personnel were equipped with MF vest transceivers that had a magnetic moment of 2.1 ATm^2 and a sensitivity of 1 V at 520 kHz. The intent of the test was to ascertain whether or not these personnel could communicate with the base at the portal, or the base at the top of the borehole. If so, it would demonstrate that MF-equipped rescue teams could communicate with the outside command center without deploying their own communications line, or relying on the integrity of the mine phone line that may, or may not, be intact. In addition, it would demonstrate that if a trapped miner was equipped with a MF transceiver of similar specifications, he or she could directly communicate with rescue teams in the mine, or search crews on the surface who were monitoring any conductors egressing the mine.

The result of the test showed that communications were possible from almost anywhere in the haulage and belt entries to either base station. It was even possible for the base at the portal, on the telephone line, to communicate with the base atop the borehole, on the fire monitor line, even though there was no physical connection between the two. Whenever a vest was within a few feet of mine conductors, there was an obvious improvement in clarity and signal strength.

Although this test was preliminary, it clearly highlights the potential of using MF communications for search and rescue operations. Much more work is necessary to measure range from mine wiring whenever the mine is not operating as would be the case during search and rescue operations. An operational mine produces considerable levels of acoustic and EM noise which reduces MF system range.

3.7.5 Emergency Warning Systems

Many types of emergency warning systems are available for alerting underground personnel. One example is the stench warning system, which introduces a distinctive odor into the airstream. Visual signals or radio paging could also be used to alert underground personnel. A preferred warning system would operate over existing wiring, such as the twisted pair of a pager phone system, and broadcast an audio warning that can be heard throughout the active areas of the underground complex. Before deciding on an alarm system, factors that affect the range over which an audio alarm can be heard should be considered. The most important factors are the noise background found in mines, the attenuation that the mine environment imposes on the alarm signal, and the attention-getting quality of different alarms.

The intensity of a sound is the energy in the sound wave. It is customary to express intensities or pressure levels in decibels. The term "loudness" refers to the response of the human ear to sound. Experiments have established that the loudness of a tone is a function of both frequency and intensity, with the ear most sensitive to frequencies in the region of 1 to 2 kHz. In other words, for tones with the same intensity, tones in the 1,000-to-2,000-Hz region appear louder than those above or below this region.

Figure 3-58 shows the noise level for a typical continuous miner, with noise samples taken at the operator's position and with the conveyor running. To estimate the masking effects of these samples, we must first transform the curves so that they refer to sound levels on a per cycle basis. This has been done in figure 3-59. The center curve, labeled "Mask noise source," plots the average of figure 3-58 in terms of the sound level per cycle of bandwidth. The upper curve, labeled "Detection threshold at noise source," shows the estimated threshold level as a function of tone frequency. The curve shows that tones

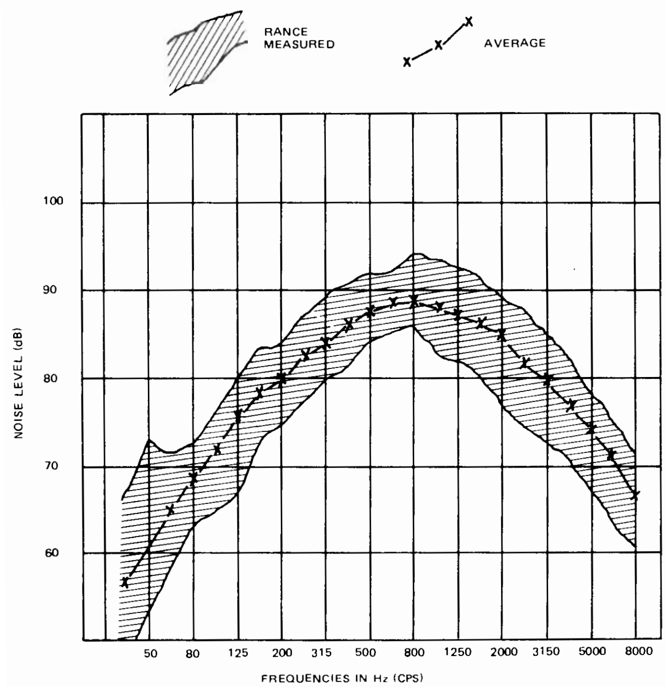

FIGURE 3-58. - Cutting with conveyor on (operator position).

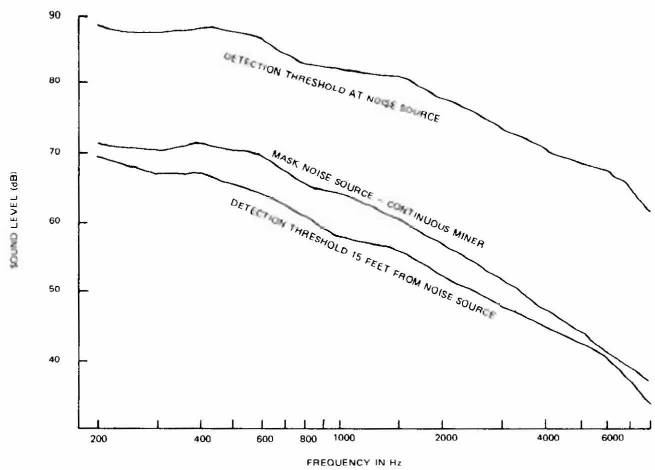

FIGURE 3-59. - Detection thresholds.

between 250 and 1,500 Hz require a level in excess of 80 dB to be just detectable. If we allow an additional 10 dB to insure detectability, alarm tones would have to have a sound level of at least 90 dB at the operator's position.

If we move 15 feet away from the operator's position (the bottom curve in figure 3-59), these sound levels are reduced considerably. This curve shows that at 800 Hz a level of 60 dB is required, and thereafter the required level decreases until at 6,000 Hz it is about 40 dB.

As mentioned earlier, the ear is most sensitive in the region of 1,000 to 2,000 Hz and decreases at higher frequencies. Figure 3-59, however, shows that the higher the frequency of a tone (up to 8,000 Hz), the more detectable it is. The spectrum of the masking noise is the cause of this apparent contradiction. The background noise is high at the frequencies where the ear is sensitive and decreases with frequency.

In addition to overcoming background noise, planners must compensate for attenuation of the warning tone. Experimental and theoretical investigations are in close agreement on the attenuation of sound in room-and-pillar mines. Figure 3-60 shows a plan of one experiment on attenuation of sound. For this experiment, a 100-dBA source was mounted at the position shown in the figure, and

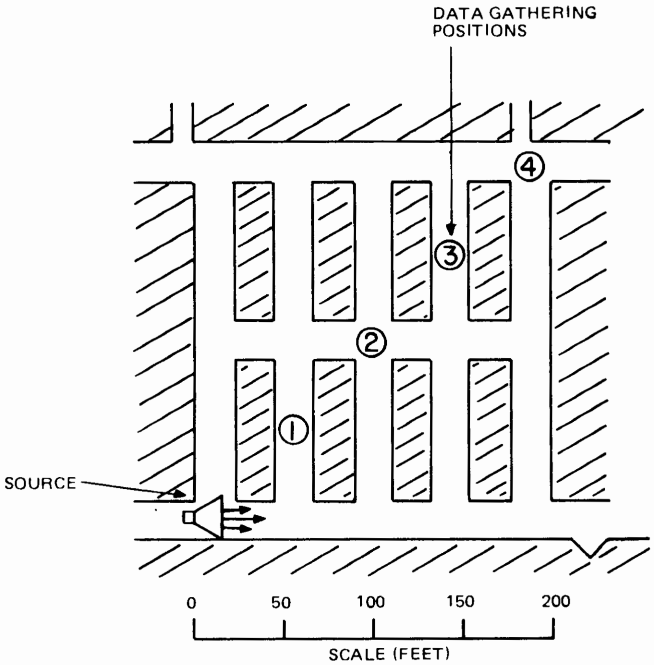

FIGURE 3-60. - Plan of mine in which experiment was conducted. (Coal seam height, 76 inches.)

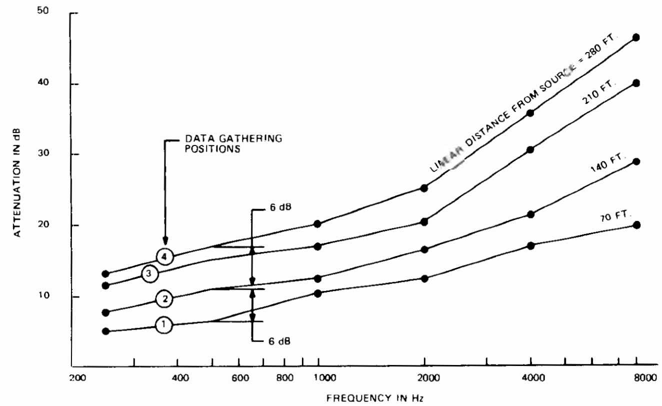

FIGURE 3-61. - Attenuation as a function of frequency.

the sound levels at the points labeled 1 through 4 were recorded. Figure 3-61 is typical of the data obtained. It plots attenuation as a function of frequency at the four points.

In practice, an audio warning source must be some distance from the personnel it is intended to alert, and it is desirable that the warning be detectable above the background noise from as far away as possible. The greater the distance the sound must propagate, the louder the source must be; hence, the greater the hazard that the source will damage the hearing of someone who is inadvertently close to it when it is actuated. In an actual emergency, the risk of subjecting a miner to intense sound may be considered justified; but to insure reliability, warning systems must be routinely tested, preferably in an operationally useful way, such as signaling the end of a shift. (Fire stations routinely test their sirens by sounding off at noon or some other prearranged time.) In addition, any system is subject to false alarms and/or pranks. Considering these factors, the presence of a really intense noise source might be regarded as an unwarrantable menace.

Table 3-4 combines the effects of background noise level and attenuation of the alarm tone to show the sound level required at the source for the warning to be just detectable by the operator of a continuous miner. The significance of these numbers is best explained by taking a particular example. The entry for 1,000 Hz under 210 feet is 100. This means that at 1,000 Hz the source level required to just alert the operator of a continuous miner who has "normal hearing" is 100 dB when the source is 210 feet away from him.

TABLE 3-4. - Sound level required at source for warning to be just detectable at operator's position on a continuous miner, dB

Frequency (Hz)	Distance from source			
	70 ft	140 ft	210 ft	280 ft
250	93	96	100	101
500	95	99	103	105
1,000	94	96	100	103
2,000	91	95	99	103
4,000	88	91	102	107

There are systems commercially available that can satisfy the requirements of audio warning systems using existing mine wiring. These systems use the mine paging telephone network as the emergency alarm system. This approach requires the addition of an alarm signal generator compatible with the pager phone operation. The paging telephone and external remote speakers act as the alarm sounding units. The alarm signal can be transmitted using a standard mine paging telephone and an acoustically coupled alarm signal generator or by using a dedicated on-line alarm signal generator, as shown in figure 3-62. Alarm signals are fed onto the pager phone line in one of two ways.

The first way uses the small portable alarm signal generator shown at the top of figure 3-62. When operated, this unit emits an audio alarm via a small speaker. The speaker is equipped with a suitably sized rubber gasket that enables the sound to be efficiently coupled into the microphone of any standard pager phone. Units of this type are commonly used in conventional telephone applications to remotely control such items as telephone answering machines and WATS line access. It can be seen that sounding an alarm in this way is a little awkward since three buttons must be pushed simultaneously, but this provides a safeguard against an accidental alarm. In addition, the portable units need only be entrusted to responsible individuals, which is a safeguard against pranksters.

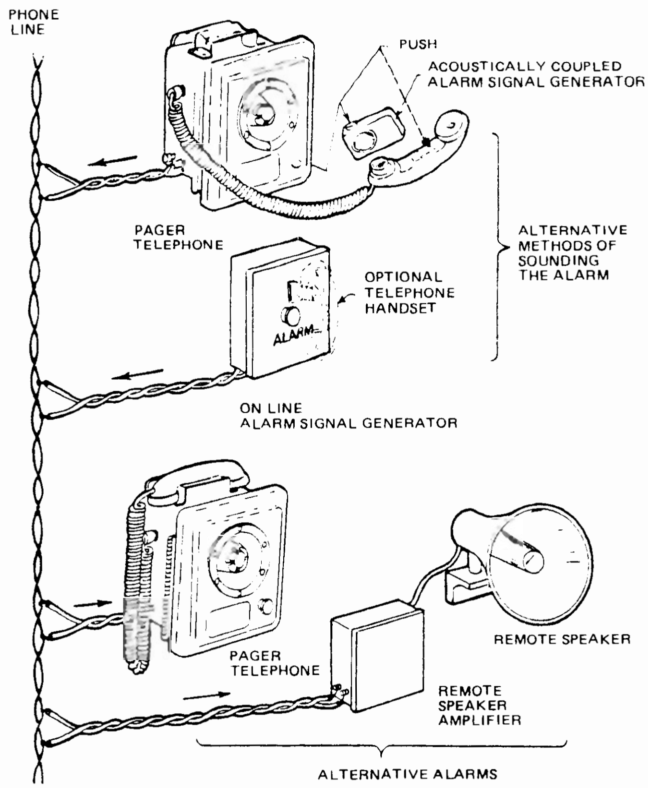

FIGURE 3-62. - Use of the existing pager telephone network as an emergency alarm system.

The second way of sounding an alarm on the system is to use the on-line alarm signal generator shown in figure 3-62. When the button on this unit is pressed, it places the correct dc signals on the line to actuate the pager phones and electronically transmits the alarm signal.

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